SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

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FHWA/IN/JHRP-82/20

CHEMICAL MOWING: A NEW MAINTENANCE CONCEPT FOR INDIANA ROADSIDES

D. James Morre

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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D. James Morre

Final Report

CHEMICAL MOWING: A NEW MAINTENANCE CONCEPT FOR
INDIANA ROADSIDES

TO: H. L. Michael, Director
Joint Highway Research Project

December 15, 1982

Project: C-36-48I

FROM: D. J. Morre

File: 9-7-9

Attached is the Final Report on the HPR Part II Study titled "Chemical Mowing: A New Maintenance Concept for Indiana". I served as the principal investigator on this study, directed the 5-year project and have authored the report.

The research results include recommendations for a single spray application which will control weeds and retard grass growth so that no further herbicide application or mechanical mowing is required for the year. The feasibility of chemical mowing is established. If adopted state-wide the economic savings over current controls could approach $1,000,000 annually or more.

We believe this study has been and will continue to be for years to come a valuable study for the state and others. We know experimental use of the recommended mixture is already in place and we believe emphasis on further implementation by the state would be of value. I would be pleased to provide advice and counsel to DOH as required.

Sincerely,

D. J. Morre/HLM

D. J. Morre

DJM:ms

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-82/20		

4. Title and Subtitle	5. Report Date
CHEMICAL MOWING: A NEW MAINTENANCE CONCEPT FOR INDIANA ROADSIDES	December 15, 1982
	6. Performing Organization Code
7. Author(s) D. James Morre	8. Performing Organization Report No. JHRP-82-20
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907	10. Work Unit No. 11. Contract or Grant No. HPR-1(20), Part II
12. Sponsoring Agency Name and Address Indiana Department of Highways State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.Study title is "Chemical Mowing: A New Maintenance Concept for Indiana"

16. Abstract

This study was to design a low-cost program of chemical mowing for Indiana roadsides. The principal objective was to develop a single chemical treatment that was inexpensive, effective, long-lasting, environmentally safe, and, except for retardation of growth, not injurious to turf and that would eliminate or substantially reduce the need for mechanical mowing.

Independently, and through the assistance of industrial cooperators, a large number of commercially available and experimental materials were examined for growth retardant activity in a series of laboratory, greenhouse and field studies. More than 500 materials were screened. From these, about 20 materials were selected for detailed study. Finally a series of test plots was established under roadside conditions to begin evaluations under field conditions. More than 3,000 test plots were evaluated. A final selection of approximately 5 materials, effective on both bluegrass and fescue, were tested in large plots, primarily along the Interstate System in combination with a second primary agent to control broad leaf weeds. Optimum rate of application at a fixed date and optimum date of application at a fixed rate were established. One of the materials tested over 4 years consistently gave the desired results in a 3-way mixture consisting of Embark (mefluidide), an additive and 2,4-D salts. A single application gave complete suppression of seed heads and the sprayed roadsides maintained a healthy lawn-type appearance well within current mowing limits. The estimated cost of the application is sufficiently low to be competitive with 2-cycle mowing.

17. Key Words	18. Distribution Statement
Chemical Mowing; Herbicides; Roadside Maintenance; Growth Retardants; Mefluidide; 2,4-D	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	110	

Form DOT F 1700.7 (8-69)

Final Summary Report

CHEMICAL MOWING: A NEW MAINTENANCE CONCEPT FOR INDIANA ROADSIDES

by

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Project No.: C-36-48I

File No.: 9-7-9

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana Department of Highways

and the

U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, Indiana
December 15, 1982

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EXECUTIVE SUMMARY

The objective of this research project, full-season vegetation control along Indiana Roadsides through a single spray application and with no need for additional herbicide application or supplementary mechanical mowing has been demonstrated to be feasible with a combination of materials commercially available,or soon to be available commercially. The recommended mixture consists of a grass growth retardant, a primary agent to control broad leaf weeds and an additive that potentiates the effectiveness of the two primary agents. The application is made during a six-week period in early spring using ordinary commercial equipment. Formation of grass seed heads is prevented and,by frost in the fall,the total height of the grass is still about 12 inches , well within the acceptable mowing limits specified by the State of Indiana. Thus, the feasibility of chemical mowing has been established.

The economics are such that the cost of the treatment is substantially less that current costs of three-cycle mechanical mowing plus herbicide treatments and is competitive with two-cycle mowing. The program has immediate applications for difficult-to-mow areas or narrow medians, guard rails, bridge approaches, etc. where both cost and safety considerations favor complete elimination of conventional mechanical mowing. With further cost reductions possible through the use of less expensive and more effective additives, widespread adoption of the recommended program is anticipated. If adopted state-wide, projected cost savings of between $400,000 and $1,500,000 annually are expected depending upon the number of actual mowings eliminated.

INTRODUCTION

Mechanical mowing of roadsides remains the most costly feature of roadside maintenance in Indiana. According to figures supplied by Kenneth Mellinger and Marion Bugh, Indiana State Highway Commission at the beginning of this project in 1977, there were 38,700 acres per cycle in the contract mowing program with an additional 24,000 acres per cycle in force account mowing by State crews. This gave a total of 62,700 acres mowed per cycle state wide. With 2-3 cycle mowing at an approximate cost of $11 per acre, mowing costs were estimated to lie between $1,000,000 and $2,000,000 annually in 1977. In the succeeding 5 years after these estimates were made, the cost of mowing more than doubled to $25 per acre per cycle.

The research which is the subject of this report was intitated on August 29, 1977. A no cost extension was approved June 15, 1982. The proposal was to design and develop a low-cost program of chemical mowing for Indiana roadsides. The treatment was to be inexpensive, effective, long-lasting, environmentally safe, and, except for retardation of growth of turf grasses, not injurious to turf. Once chemical mowing was realized, the projected cost savings were projected to be in excess of $1,000,000 annually.

At the time the project was initiated, there were few, if any, practical chemical retardants of grass growth on the market. Most were inhibitors of cell division (Figure 1). They inhibited the number of cells produced by the plant but had little or no effect on ultimate cell size. Because of the fundamental nature of the division process, division inhibitors, as a class, result in a weakened root system and fewer internodes but normal elongation of those cells that are present or produced. The end result is weakened plants, a turf susceptible to development of wear areas, and treatments that are unreliable with timing of application critical, sensitive to climatic factors, and, if applied at economic rates with commercial equipment, prone to produce uneven effects.

In contrast, elongation inhibitors will produce plants with normal numbers of shortened cells. The number of internodes will be the same but the internodes will be closer together (Figure 2). Since the elongation mechanisms of roots and shoots seem to differ in fundamental respects, a shoot-specific elongation inhibitor is a real possibility. With such a compound, the result would be a sturdy plant of normal proportions--only shorter. The plant would remain healthy, require less fertilizer, and have a stronger root system than its uninhibited counterpart.

To avoid problems with proprietary products, no development of new materials was to have been attempted under this project. Testing was limited to compounds available commercially, those under commercial development and obtained through industrial cooperators or compounds where synthesis and testing was carried out under another research project.

The project has been completed successfully. Not only has the feasibility of single application chemical mowing been demonstrated but a combination of three materials has been developed that is cost-effective and competitive with two-cycle mowing. The end result is expected to be full-season management of roadside vegetation including control of broad-leaf weeds with a single spray application. Mechanical mowing should not be required if the chemicals are applied correctly. Implementation of recommendations is scheduled for the spring of 1983.

The report is divided into four sections following the introduction. Phase I deals with the selection of materials for initial field evaluation and the identification of retardant potentiating compounds. This work relied heavily on preliminary studies from another project and covers the time period 1977-1978. The basic retardant material was selected during these years and the concept of potentiating additives was developed. Phase II was concerned with the efficacy of a 3-way mixture of primary growth retardant + additive + herbicide. Initiated in 1978, this work was continued for 3 years with completion in 1980. The major contribution was to demonstrate that chemical mowing was feasible using existing materials. Because the actual mixture tested will not be recommended in the forseeable future, the results are somewhat abbreviated and only major findings substantiated by data.
In phase III (1981-1982), a concerted effort was initiated to search for new synergistic additives to enhance efficacy of Embark (mefluidide)-2,4-D mixtures. This work is presented in more detail as it provides the basis for the current recommendations summarized in Phase IV.

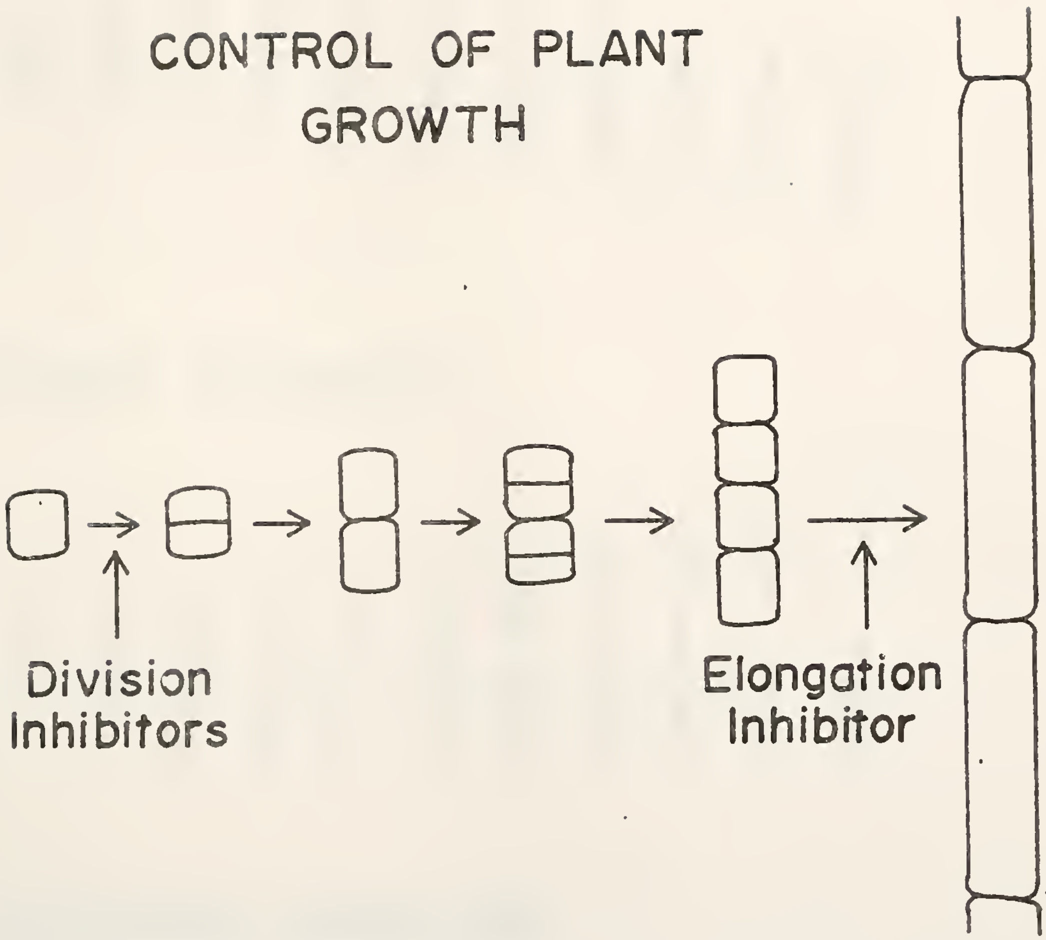

Figure 1. Diagrammatic representation of plant growth as the summation of two cellular events--division and elongation. Arrows indicate sites of action of inhibitors which function as growth retardants.

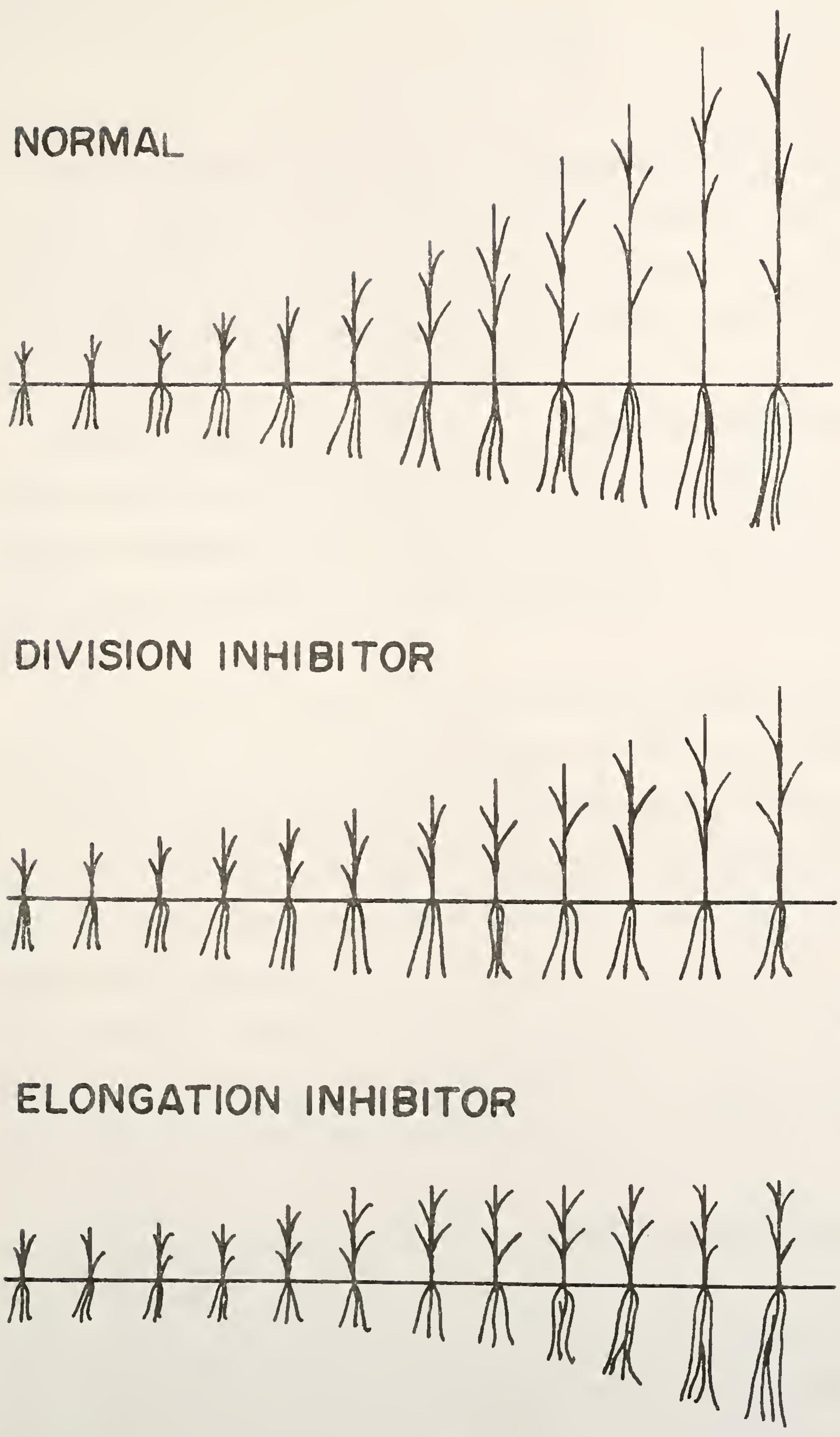

Figure 2. Diagrammatic comparison of the mode of action of a cell division inhibitor with that of a cell elongation inhibitor in the regulation of grass growth.

BACKGROUND

Chemical mowing is the outcome of a program of research in roadside vegetation management initiated for the State of Indiana in 1966 under the Joint Highway Research Project and in close cooperation with the Indiana State Highway Commission. The research has evolved through four phases listed in Table 1.

The first research phase, from 1966 to 1970, was largely one of problem identification in which surveys were conducted to evaluate practices of vegetation management then current and to identify specific needs that, if met, would be expected to result in significant cost savings to the state.

The second phase, development of a herbicide program, was the first to be implemented. The program was begun in 1971 with full implementation in 1972-1973. A fall application of an environmentally safe amine formulation of 2,4-D is followed by a second application in early spring on a 3-year rotation. This program has been in continuous operation for more than a decade and has been most successful (1).

Research on Phase III "Reduced Mechanical Mowing" was initiated in 1971 with the first implementation activities in 1974. A report on this phase was made in 1978 (2) and remains the basis for current mechanical mowing practices in Indiana.

The project now entering the first phase of implementation, Phase IV, and the subject of this report, is "Chemical Mowing." The objective was to develop and test materials or mixtures of materials that would eliminate or reduce the need for mechanical mowing and provide efficient total vegetation management at reduced costs to the State.

Table 1. Indiana Program of Roadside Vegetation Management

Phase	Designation	Begin	End	Total Study Costs	Cumulative First Year Cost Savings
I	Problem Identification	1966	1970	$25,000	none
II	Herbicide Program	1971	1973	$30,000	$300,000
III	Reduced Mechanical Mowing	1974	1976	$45,000	$1,100,000
IV	Chemical Mowing	1977	1983	$125,000	$2,000,000*

*Projected

THE CONCEPT OF CHEMICAL MOWING

As the name implies, chemical mowing is the use of chemicals to prevent or reduce the growth of vegetation so that the need for mechanical mowing either is eliminated or reduced. Some of the characteristics of the desired treatment are summarized in Table 2.

Ideally, one would anticipate a single spray application that would maintain maximum grass height below acceptable mowing limits. For use in Indiana, it must be effective against both fescue and bluegrass, the dominant turf species in the state, as well as give control of broad-leaf weeds and brush species. Tall annual grasses such as giant foxtail also must be controlled; a pre-emergence action that prevents the germination of annual grass seeds in the spring is one approach that offers considerable promise.

In addition to the above criteria, it is important that the treatment be environmentally safe. There should be no weakening of the root system of the grass, no injury to desirable species and no carry-over that would limit repeated annual use. A healthier, lawn-type appearance to the turf would be ideal. Finally, the treatment must be practical from an economic standpoint. The total cost of a single spray application must not exceed the current maintenance costs. For Indiana this consists of the fall-spring spraying rotation and limited 3-cycle mowing. If possible, the treatment should be designed to be not only cost-effective but to provide substantial cost savings.

The most important criterion, however, is that of seed head suppression. Most roadsides require mowing to control seed heads, especially with fescue. If even a few seed heads form, the appearance is unsightly. For whatever treatment is used, the elimination of seed heads is essential.

Table 2. Desired Characteristics of a Program of Chemical Mowing

1. Single spray application
2. Control of broadleaf weeds/brush/annual grasses
3. No seed heads formed in turf species
4. Maximum grass height below acceptable mowing limits
5. No mechanical mowing necessary
6. No weakening of root system; no untoward injury to desirable species; repeated annual use possible
7. Healthy, lawn-type appearance
8. Low cost
9. Environmentally safe

METHOD OF APPROACH

In this section the overall method of approach is summarized. Details of specific studies and tests are provided throughout the body of the report in conjunction with the results obtained.

In the initial phase of the study, more than 500 materials were screened and examined for growth retardant activity in a series of laboratory, greenhouse and field studies. These compounds were obtained independently and through the assistance of several industrial cooperators. From the more than 500 materials examined, about 10 materials were selected for detailed study.

Finally, a series of test plots was established under roadside conditions to begin to evaluate the 20 growth retardant materials and combinations selected from the preliminary laboratory and greenhouse testing. More than 3,000 plots were evaluated. Included in the evaluations were degree of growth retardation, effects on seed head suppression, color, vigor, and growth of underground parts and mode of action. Measurements of individual plant parts were taken at weekly or biweekly intervals to help understand how grass growth was being affected. Emphasis was on evaluating how growth was retarded, for how long, and to what extent. Any material showing promise on one species was tested on other species as well. Approximately 5 materials, effective on bluegrass and fescue, were selected for detailed evaluation in combination with a second primary agent to give control of broad leaf weeds.

The approximately 5 materials to be evaluated in more detail were tested in large plots, primarily along the Interstate System, for optimum rate of application at a fixed date and for optimum date of application at a fixed rate. Date studies were initiated about every two weeks from early March to mid-September in the first years and from early March to early June in later years. Rate studies were conducted in early, mid and late spring, mid summer, and early fall in the first years and in early, mid and late spring in the three succeeding years. Several potentiating additives were also evaluated.

Because much of the early work was exploratory and did not lead to treatments that could be implemented, specific details are not included in the final summary report. Some of the early work with additives, while not leading to implementable recommendations, did serve to illustrate the feasibility of chemical mowing and establish principles important to the overall concept and is, therefore, included. Most of the report, however, focuses on important findings that provide the basis for the final recommended maintenance program suggested for implementation.

The basic approach followed and the numbers of materials evaluated in each of the various testing phases are summarized in table 3.

Table 3. Summary of Methods of Approach

Combined Laboratory, Greenhouse & Field Studies	
More than 500 materials screened	
About 10 materials tested intensively alone and in various combinations	
More than 3,000 test plots evaluated	
EMBARK + Additive + 2,4-D Amine Combination	
4 years field experience	
Rate of application at fixed date	
Date of application at fixed rate	
Two species:	Tall fescue
	Kentucky bluegrass
Different additives compared	

P H A S E I

SELECTION OF MATERIALS FOR INITIAL FIELD EVALUATION AND IDENTIFICATION OF RETARDANT POTENTIATING ADDITIVES

1977-1978

1. Scope and objectives.--This phase of the study was based on extensive laboratory and greenhouse investigations and information obtained through the assistance of industrial cooperators in which more than 500 different compounds were evaluated for possible inclusion in a growth retardant mixture for use along Indiana roadsides. The overall object was to demonstrate feasibility of chemical mowing and to provide a basis from which a recommended treatment combination might be developed.

2. Introduction.--What was proposed was to develop a chemical treatment which,when combined with the herbicide mixture of the Herbicide Spraying Program by Contract in the spring application, will specifically retard the growth of the grass. By combining the two treatments, application costs would be minimized. Even with a relatively costly material, it was reasoned that a cost saving might result if even only one mowing were eliminated.

The experimental materials were already in hand when the project was initiated. Extensive testing, however, was anticipated to establish effectiveness, cost, timing of applications, compatibility with herbicides, long-term effects on turf, enrironmental safety, and to select the final material of choice from approximately 10 to 20 potential candidates. Once a tentative selection of a set of materials was made, the next step would be a gradual introduction into the State Maintenance Program, followed by an evaluation period of minimally, 3 to 5 years.

Additionally, it was necessary, under this phase of the study, to develop criteria that would permit meaningful comparisons and evaluations of selective retardants of grass growth and to devise experimental methods to evaluate these criteria quantitatively. Methods to be evaluated included:

1) Degree of growth retardation
2) Degree of seed head suppression
3) Effects on color
4) Reduction or enhancement of vigor
5) Effects on underground plant parts
6) Mode of action.

3. Method of approach: The materials selected initially for intensive testing are listed in Table 4. These included two primary growth retardants, several potentiating additives and four standard herbicides. Of the potentiating additives, the K-series were introduced first in 1977 followed in 1982 by IN-II and XM-12S when it became apparent that it was impractical to obtain K-104 in sufficient quantities at a reasonable price to continue large scale field testing.

For the most part, applications were to small plots using a compressed air sprayer. Applications were in water at 40 psi and 40 gallons of total spray solution per acre were applied.

Grass heights were recorded in inches and represent an average of several measurements of the mean maximum height (essentially the mean height plus one standard deviation). Measurements were recorded usually at weekly or biweekly intervals.

Enviornmental safety studies also were carried out with additives K-104 and K-105. Test parameters included feeding studies with mice, fish toxicity studies and mutagenicity (carcinogenicity) testing with Salmonella strains (Ames test).

Table 4. Listing of Materials Tested Intensively

Primary Growth Retardants	
1.	Embark (Mefluidide)
2.	Sustar
Potentiating Additives	
3.	K-104
4.	K-105
5.	IN-II
6.	XM-12S
Herbicides	
7.	2,4-D amine
8.	Lithium 2,4-D
9.	Banvel (Dicamba)
10.	Tordon (Picloram)

4. Major findings: A significant outcome of early laboratory and greenhouse studies was the observation that certain chemicals, themselves devoid or nearly devoid of growth retardant activity, could potentiate or increase the activity of several primary growth retardants in mixtures. Results are shown in Figure 3 for two growth retardants, Embark and Sustar, and an additive designated as K-105. On the abscissa are indicated the proportion of the two components, additive and retardant, in the mixture. At the extreme right there is only additive and no retardant. This treatment is inactive. At the extreme left there is only retardant and no additive. About 50% inhibition of growth of bluegrass in the greenhouse was obtained. However, mixtures of equal parts of the additive and retardant were just as effective as retardant alone. This becomes important for three reasons. If the cost of the additive is significantly less than that of the retardant, considerable cost savings can result by using additive + retardant mixtures. Secondly, toxicity may be reduced in additive + retardant mixtures compared to retardant alone. Thirdly, the use of additives tends to "flatten-out" the dose-response curves so that uniformity of response becomes less dependent upon an absolutely uniform application of material.

Tests continued in the field in 1977 on mowed stands of bluegrass and fescue confirmed the laboratory and greenhouse observations. Embark was applied to bluegrass at four rates of application in the absence (dashed line) or presence (solid line) of another additive K-104 (Fig. 4). Note that vegetative growth was suppressed to a much greater degree by Embark plus additive than by Embark alone. Similar results were obtained with fescue (Fig. 5). Note also that, with fescue, the dose-response curve to Embark alone (dashed curve) is fairly steep. It does not begin to flatten out until rates of 1 lb/A or higher are reached. In contrast, the Embark plus additive curve (solid line) is flat. At ½ lb/A of Embark + 1 lb/A of K-104, the rate could be varied by a factor of two without any change in grass height. The latter is a most

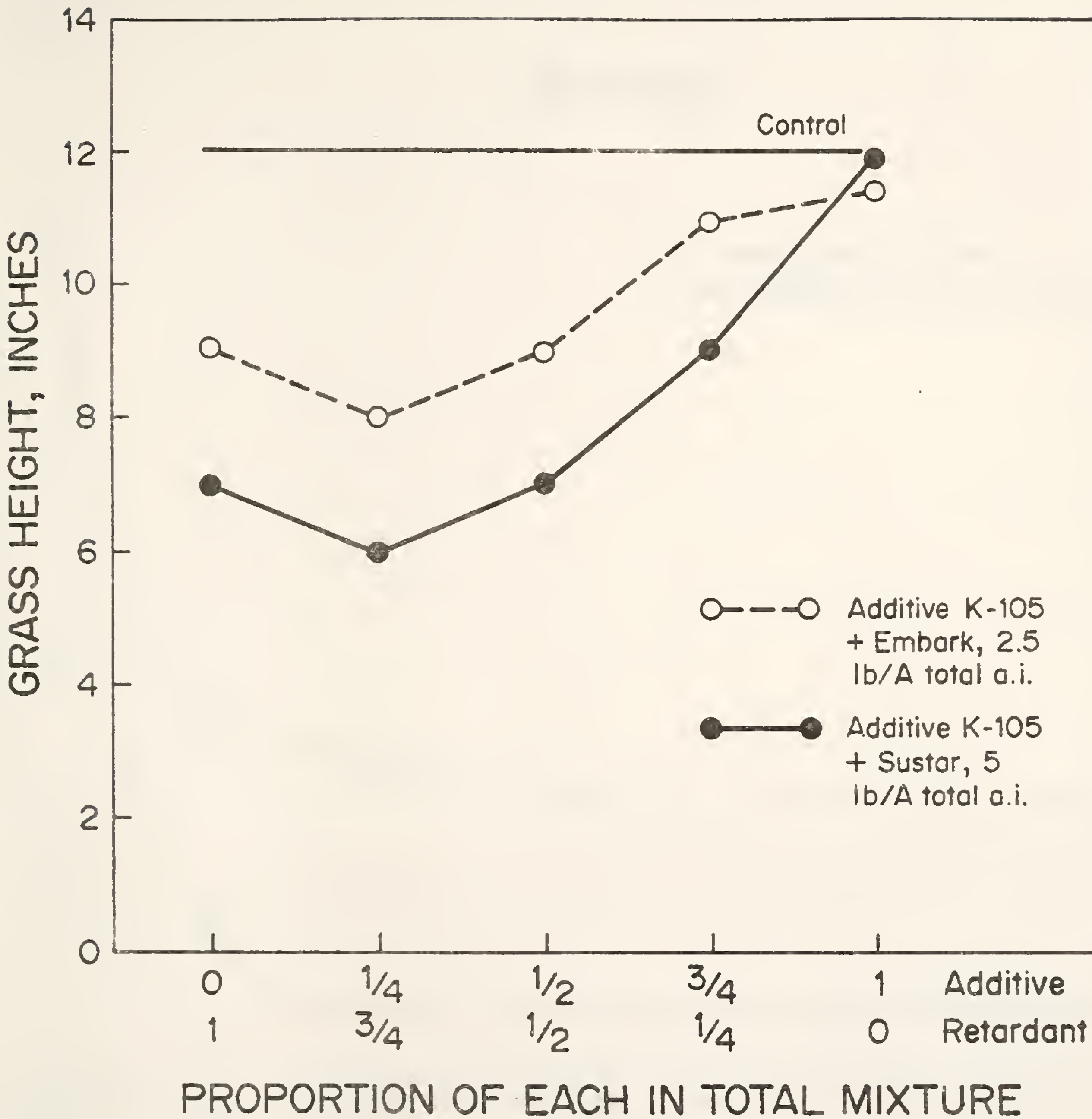

Figure 3. Comparisons of mixtures of two retardants and a potentiating additive (K-105) on growth of bluegrass in the greenhouse.

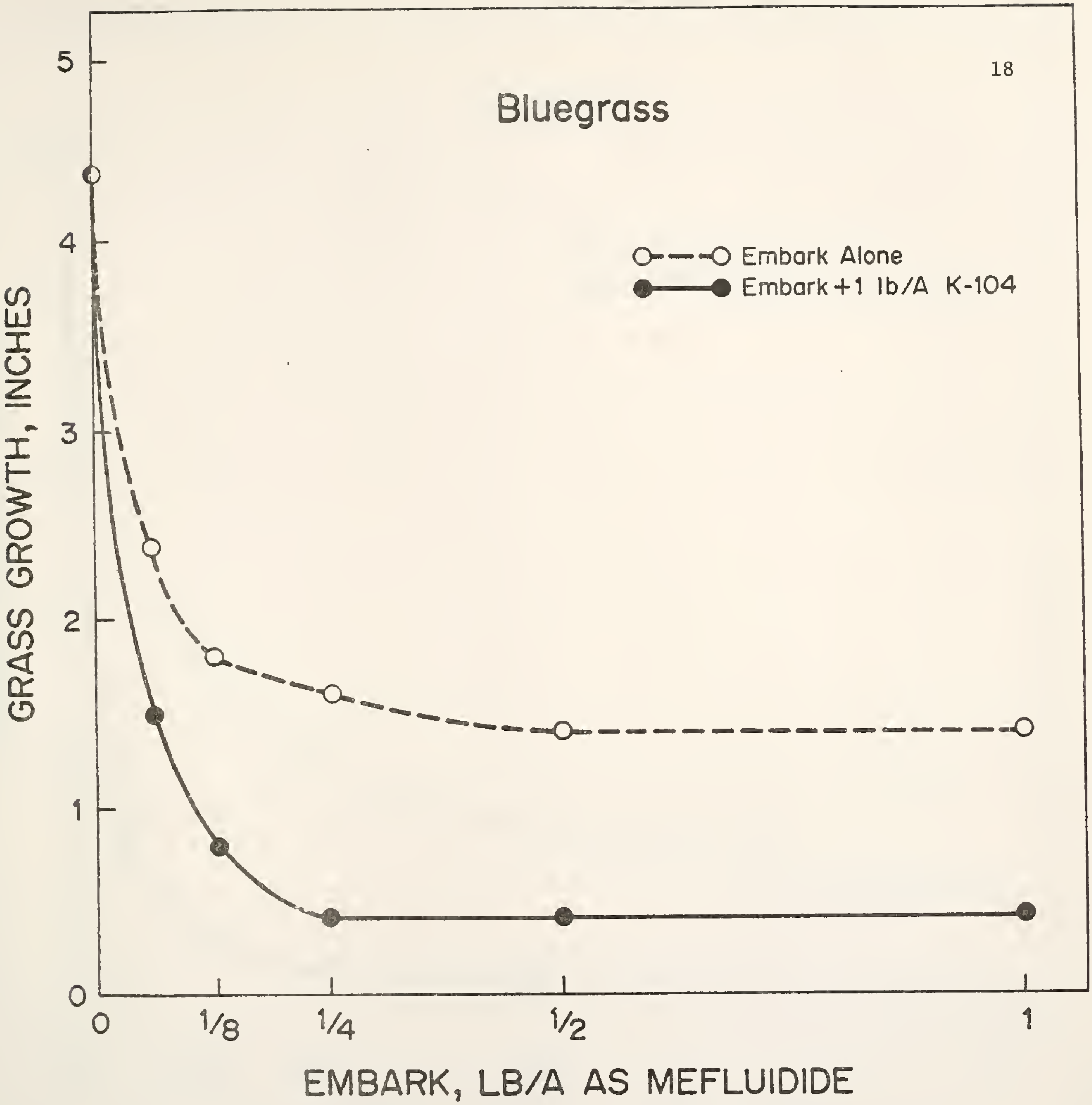

Figure 4. Synergism between various rates of Embark (upper dashed curve) and Embark plus 1 lb/A of additive K-104 (solid lower curve) on growth of bluegrass comparing various rates of Embark in the mixture. Treatments were applied on August 30, 1977 with measurements on November 3, 2 months after application.

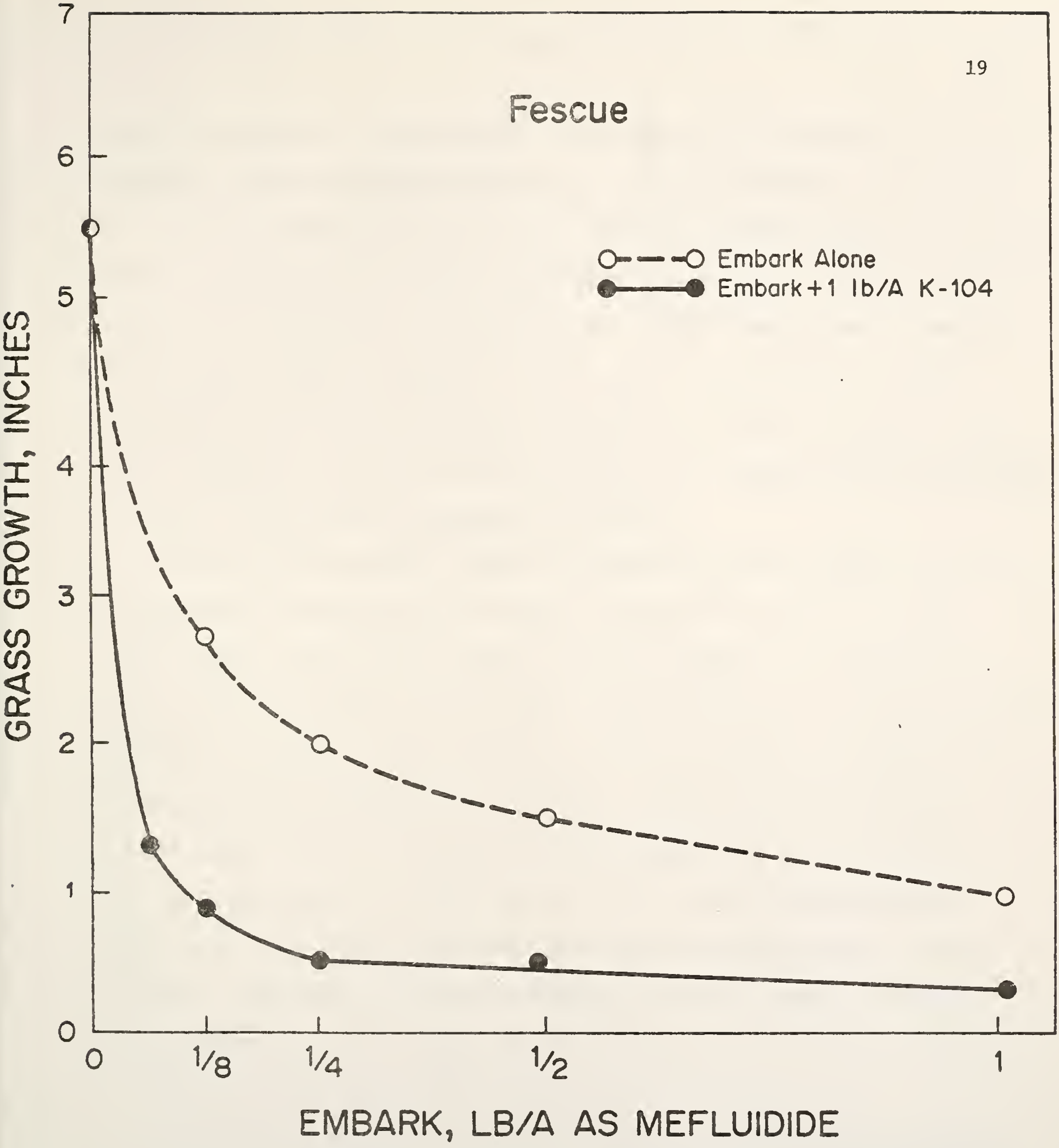

Figure 5. Synergism between various rates of Embark (upper dashed curve) and Embark plus 1 lb/A of additive K-104 (lower solid curve) on growth of fescue. Treatments were applied on August 30, 1977 with measurements on November 3, 2 months after application.

desirable feature of a grass growth retardant mixture for roadside use where absolutely uniform applications will be difficult to achieve.

As in the greenhouse (Fig. 3), the potentiating additives K-104 and K-105 alone had no effect on growth of mowed bluegrass or fescue in the field (Table 5). Similarly, the herbicide 2,4-D Amine did not inhibit grass growth. However, in these tests, there did appear to be a potentiating interaction between the additive K-104 and 2,4-D amine but not between additive K-105 and 2,4-D. The two additives K-104 and K-105 when mixed did not demonstrate any interaction in terms of inhibition of grass growth (Table 5).

A practical consideration coming from these early field studies in 1977 and confirmed in subsequent years (Table 6) was that the margin of safety of the Embark retardant was increased greatly by additive K-104 in addition to the effacacy response already noted. Embark alone was toxic to some strains of native bluegrass at rates as low as 1 lb/A. In at least one field trial, fescue was killed at Embark rates of 2 lb/A. However, the same stands of native bluegrass that were killed by 1 lb/A Embark alone were not killed by the mixture of K-104 plus Embark until the Embark amount reached 2 lb/A. Additionally, the use of the additive decreased the effective dose of Embark by nearly a factor of two. The end result, in terms of margin of safety, was an increase from 4 to about 16 for both bluegrass and fescue as summarized in Table 6.

Not only were the Embark plus K-104 mixtures more effective in reducing the growth rate of bluegrass and fescue but the delay before growth was resumed was greater especially in hot weather. Data obtained in July 1977 is summarized in Figures 6 and 7. With bluegrass (Fig. 6), untreated grass grew at a nearly linear rate of 1 inch per week. With ½ lb/A Embark alone, growth stopped entirely for nearly three weeks and then resumed at a near normal rate. With the same rate of Embark (½ lb/A as mefluidide) plus 1 lb/A of K-104, growth

Table 5 . The Potentiating Additives, K-104 and K-105, Do Not By Themselves Inhibit Grass Growth, Nor Does 2,4-D. Treatments were applied August 25, 1977 to triplicate 3 ft X 3 ft plots. The intial grass height was 7 inches and was mowed previously to a height of 3 inches. Measurements were taken on September 15, 1977 about 3 weeks after treatment application.

Chemical		Rate**	Grass height, inches	
Additive	Herbicide	lbs/acre	Bluegrass	Fescue
None	None	-	12	13
K-104	None	1	12	11
None	2,4-D Amine	2.5	12	13
K-104	2,4-D Amine	1 + 2.5	9*	9
K-105	None	2.5	12	12
None	2,4-D Amine	2.5	12	13
K-105	2,4-D Amine	2.5 + 2.5	11	12
K-104 + K-105		1 + 2.5	11	11

* Significantly different from the untreated control. All other differences were within the range of errors among replicates.

** Pounds per acre of active ingredient.

Table 6 . Practical Margin of Safety Comparing Embark Alone and In Combination With Potentiating Additive K-104. Values are estimates obtained from toxicity data obtained during the summer of 1977 and efficacy data over the period 1977 to 1981.

	lb/acre of Embark				Practical	
	Effective dose E.D.$_{50}$**		Potentially toxic dose L.D.$_{50}$***		margin of safety	
Treatment	Bluegrass	Fescue	Bluegrass	Fescue	Bluegrass	Fescue
Embark Alone	1/4	1/2	1	2	4	4
Embark + Additive K-104*	1/8	1/4	2	2	16	16

* The rate of additive K-104 is constant at 1 lb/A. All rates are active ingredient.

** Rate to give 50% reduction in seed heads (rate of blade elongation).

*** Rate to give 50% reduction in stand. This value is dependent upon climatic factors following application, the stage of growth when applications are made, and especially differences among grass varieties. While some native bluegrass was especially susceptible to killing by high doses of Embark (e.g. 1 lb/A), most lawn varieties of bluegrass were much more resistant.

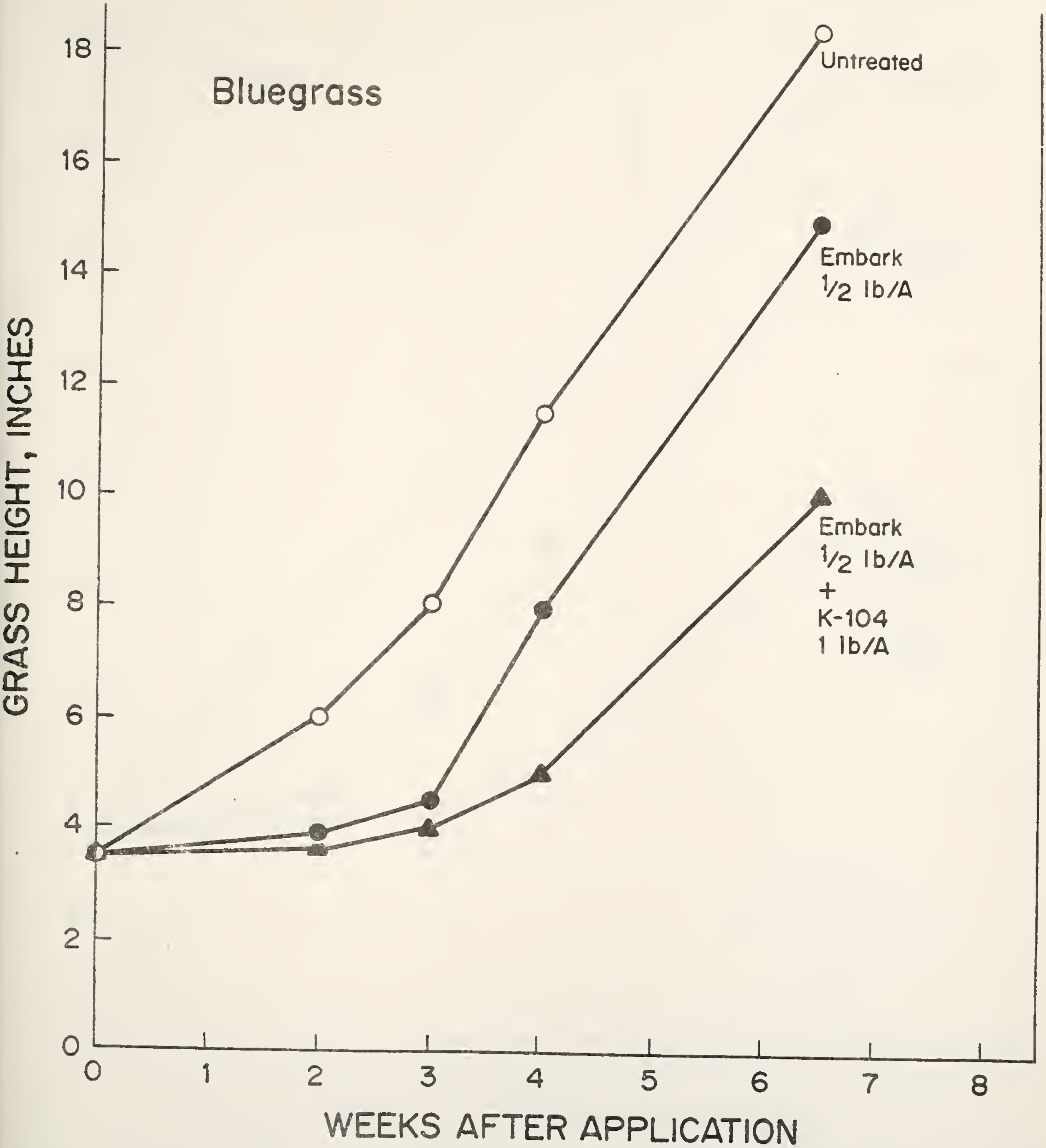

Figure 6. Time course of growth of bluegrass comparing Embark with Embark plus additive K-104. Treatments were applied on July 27, 1977 to grass mowed to an initial height of 3 to 4 inches.

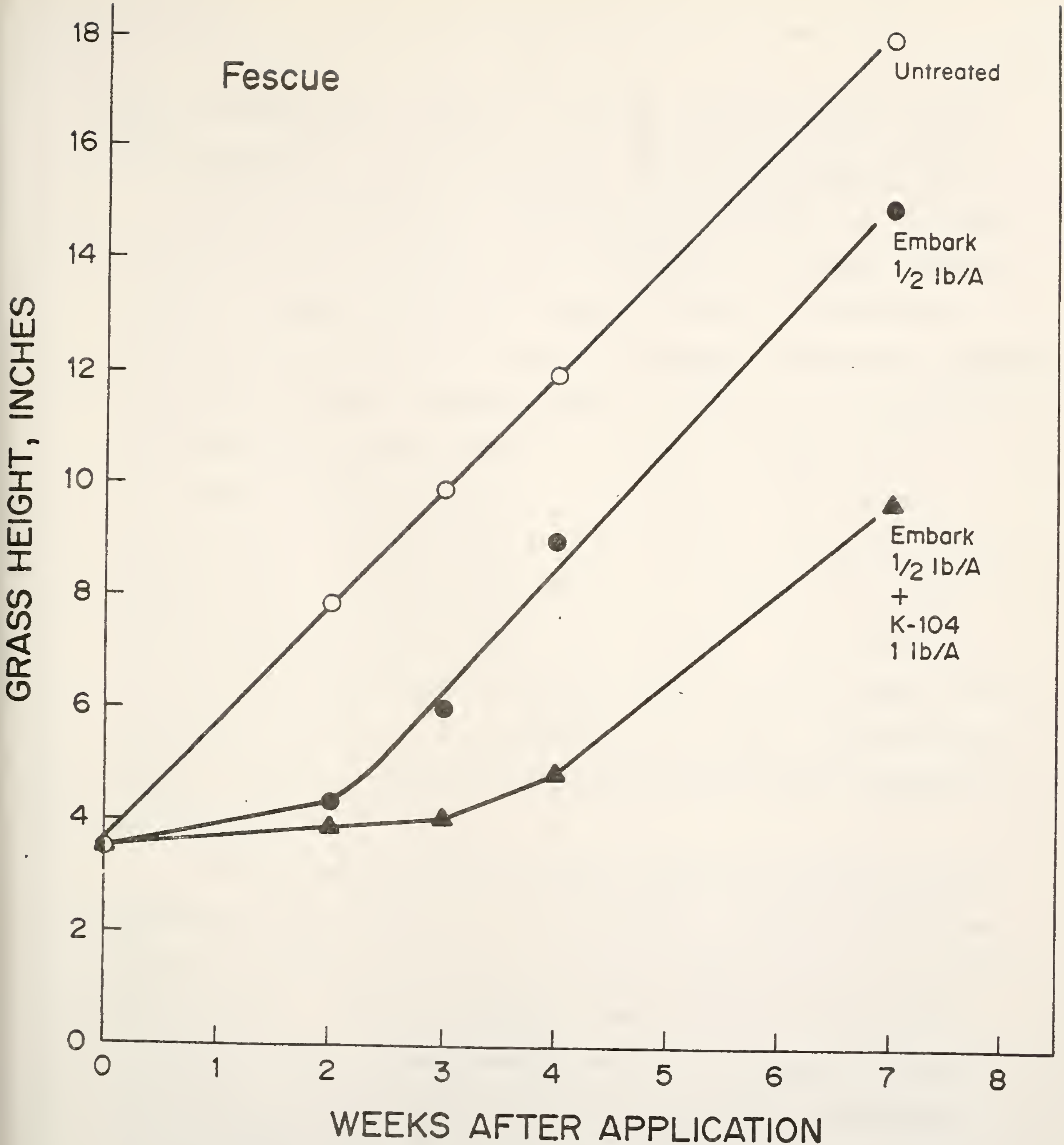

Figure 7. Time course of growth of fescue comparing Embark with Embark plus additive K-104. Treatments were applied on July 27, 1977 to grass mowed to an initial height of 3 to 4 inches.

did not resume until 4 weeks after treatment and then at a rate about half that of Embark alone. With fescue, similar results were obtained (Fig. 7).

One of the requirements of a practical growth retardant for use along roadsides set at the beginning of the study was that the compound should not inhibit root growth. Measurements summarized in Table 7 for Embark and additive K-104 show that this retardant and retardant plus additive combination fulfill this criterion. Treatments applied in March, April, May and June were compared with sampling during the first week of August in 1977. At all dates of Embark application, no adverse effect on root growth was noted. In fact, roots were slightly longer in some of the treatments where Embark + K-104 or K-105 additives were used. Additionally, the retardant Sustar also did not inhibit growth of roots (Table 7). Since each of the retardant or retardant-additive combinations did reduce shoot growth without inhibiting root growth, in all examples the root to shoot ratio was improved for all retardant or retardant-additive combinations relative to untreated grass (Table 7).

A problem identified early in these studies was an antagonism between Embark and an amine formulation of 2,4-D (Table 8). The first indications of such an antagonism were noted in treatments applied in early June of 1977 in small plots. This was subsequently repeated and data obtained from an August 25 treatment to mowed bluegrass and fescue is presented in Table 8. The antagonism was most pronounced at 1/8 lb/A of Embark (as mefluidide) and less evident at 1/2 lb/A of Embark (as mefluidide).

A number of different herbicide, especially in combination with additive K-104 were subsequently tested. One especially promising combination was a mixture of Embark plus additive K-104 plus the lithium salt of 2,4-D (Li-2,4-D). This mixture was as effective as Embark plus K-104 in combination and more effective than the same mixture with 2,4-D amine (Table 9).

Table 7. Effect of Selected Growth Retardants and Potentiating Additives on Roots and Shoot Growth of Bluegrass and Root:Shoot Ratios. Plugs 6 inches square were removed to a depth of 16 inches, soil was removed by washing and extended root lengths were measured. Samples were collected during the first week of August (1977).

Chemical		Rate	Length (inches)		Root:Shoot
Retardant	Additive	lbs/acre, a.i.	Shoot*	Root	Ratio**
None	None	-	18	13	0.7
	Treatments applied the first week of June in 1977				
Embark	None	1/8	11	13	1.1
Embark	K-104	1/8 + 1	8	14	1.8
None	K-104	1	14	15	1.0
	Treatments applied the last weeks of April and first week of May				
Embark	None	1/8	14	14	1.0
Embark	K-104	1/8 + 1	12	14	1.2
	Treatments applied the last week of March in 1977				
Embark	K-105	1/8 + 1	13	12	0.9
Sustar	K-105	1 + 1	12	13	1.1
None	K-105	2.5	14	14	1.0
		5	14	14	1.0

* Extended blade length only. Some treatments prevented seed head formation while others did not.

** A number less than 0.7 would indicate an adverse effect on root growth. If anything, the treatments listed seemed to favor a healthy root system.

Table 8 . Antagonism Between Embark and An Amine Formulation of 2,4-D. Treatments were applied on August 25, 1977. Measurements were made on September 15, 1977 about 3 weeks following application. Initial grass heights were 7 inches. The grass had been mowed previously to a height of 3 inches.

Chemical		Rate	Grass Height, Inches	
Retardant	Herbicide	lbs/acre, a.i.	Bluegrass	Fescue
None	None	-	9	10
Embark	None	1/8	6	7
Embark	2,4-D Amine	1/8 + 2.5	8*	9*
Embark	None	1/2	7	7
	2,4-D Amine	1/2 + 2.5	7	8

* Note that the addition of 2.5 lb/A 2,4-D amine to the Embark, especially at the lower rate of application of 1/8 lb/A, reduced considerably the effectiveness of the Embark to retard the growth of both bluegrass and fescue.

Table 9. Effect of Various Herbicides for Control of Broad-Leaf Weeds on Retardation of Growth of Mowed Bluegrass and Fescue by 1/8 lb/A Embark. Applications were in July 1977. Measurements were taken during the first week of August, 1977. Grass height at the time of treatment was 3.5 inches.

	Chemical		Rate	Grass Height, Inches	
Retardant	Additive	Herbicide	lb/A	Bluegrass	Fescue
None	None	None	-	5	6
Embark	None	None	1/8	4.5	5.5
Embark	K-104	None	1/8 + 1	4	5
Embark	K-104	2,4-D Amine	1/8 + 1 + 2.5	5	5.5
Embark	K-104	Li 2,4-D	1/8 + 1 + 2.5	4	5
Embark	K-104	Tordon	1/8 + 1 + 2	4.5	6
Embark	K-104	2,4-D Amine	1/8 + 1 + ½	4.5	5.5
Embark	K-104	Tordon	1/8 + 1 + ½	5	6
Embark	K-104	Li-2,4-D	1/8 + 1 + ½	4	5
Embark	K-104	Banvel	1/8 + 1 + ½	5	5.5
Embark	K-104	Amiben	1/8 + 1 + ½	4.5	5.5
Embark	K-104	Krenite	1/8 + 1 + ½	4	6
Embark	K-104	TBA*	1/8 + 1 + ½	5.5	6
Embark	K-104	2,4,5-TP	1/8 + 1 + ½	4.5	5

* Trichlorobenzoic acid (2,3,6-)

The environmental safety of additives K-104 and K-105 was investigated in considerable detail. For KG 105, the LC_{50} to green sunfish was determined to be 146 ppm (active ingredient of the forumlated material). Swelling of mucuous membranes was observed; fish recovered from sublethal doses. The solubility of KG 105 in water was estimated to be about 400 ppm. The LD_{50} (oral, single dose) to mice of KG 105 was about 2,400 mg/kg body weight.

KG 104 was not toxic to green sunfish at 400 ppm which greatly exceeded the solubility of the material in water. This compound was not toxic to mice at 10,000 mg/kg body weight (the greatest amount tested).

Neither kG 104 or KG 105 showed evidence of mutagenicity or carcinogenicity in the Ames assay. The Ames test was carried out by the Carcinogen Testing Laboratory of the Purdue Cancer Center.

While the additive KG 105 as safe, K-104 was completely non-toxic both to mammals and fish. Neither compound affected the growth of algae at or near the solubility in water so that injury to the environment by introduction into ponds, lakes or streams could be discounted completely. Based on the laboratory tests, neither additive would be expected to cause cancer or any adverse effects to the human body under normal use conditions.

5. Research implementation.--Findings from this phase of the investigation led to large scale testing of the combination of Embark plus additive K-104 plus the lithium salt of 2,4-D (Li-2,4-D) in the next phase of the study and, eventually, to demonstration of the feasibility of chemical mowing for control of roadside vegetation. Steps were initiated to encourage the manufacture of K-104 by a commercial company and to ensure the availability of Li-2,4-D. Both K-104 and Li-2,4-D turned out to be too expensive to be included in the final recommendation but they were important components of the early mixtures and were the basis leading to the general principle of using additive-retardant combinations

and of mixing additive, retardant and herbicide to achieve both grass retardation and elimination of broad-leaf weeds.

6. Summary.--The following points were established during the first phase of the study:

1) Embark (and Sustar) was identified as a primary retardant of grass growth with desirable characteristics for inclusion in a program of roadside vegetation management.

2) Potentiating additives (K-104 for Embark and K-105 for Sustar) were identified that would reduce by one-half the amount of retardant required to achieve a given level of grass growth retardation.

3) The potentiating additives were not in themselves growth retardants under field conditions (activity was demonstrated in laboratory tests).

4) The additives increased the margin of safety of Embark on bluegrass and fescue by a factor of 4.

5) Additionally, the additives resulted in a flatter dose-response curve so that, at 1/2 lb/acre of Embark (as mefluidide), the rate could be varied by a factor of two withount any change in grass height.

6) An antagonism was observed between Embark and 2,4-D Amine (a herbicide included to control broad-leaf weeds).

7) The antagonims was reduced or eliminated in a combination of Embark plus K-104 plus the lithium salt of 2,4-D (Li-2,4-D).

8) A treatment consisting of 1 lb/A of Embark plus 1 lb/A of K-104 and 2.5 lb/A of Li-2,4-D was selected for more extensive evaluation in 1978.

9) The environmental safety of additives K-104 and K-105 was evalutated and both are to be regarded as safe.

7. Reports: Morre, D. James, "Five-Year Evaluation of Highway Mowing Practices in INdiana." A summary of activities under the previous project and a discussion of the potential of chemical growth retardants was presented at the Transportation Research Board Meetings in Washington, D.C. on January 18, 1978 and submitted for publication in the TRANSPORTATION RESEARCH RECORD.

PHASE II

EFFICACY OF A THREE-WAY MIXTURE OF PRIMARY GROWTH RETARDANT - ADDITIVE - HERBICIDE 1978 - 1980

1. Scope and objectives.--During the period 1978-1980 emphasis was on demonstrating the feasibility of chemical mowing using a 3-way mixture of a primary growth retardant (Embark) plus an additive (K-104) and a herbicide to control broad leaf weeds (Li-2,4-D). A secondary objective was to determine if, and under what conditions, the 3-way mixture could be implemented as part of the contract spraying program for the State of Indiana as a practical approach to management of roadside vegetation.

2. Introduction.--In 1977, extensive laboratory and greenhouse evaluations of more than 500 materials were reduced to practice in small plot tests under field conditions. The general principle of using an inexpensive additive to reduce the amount of a more expensive primary retardant material was introduced. One additive was selected for detailed investigation (K-104). K-104 reduced the amount of Embark (a primary retardant) required by nearly a factor of two, increased the margin of safety of the treatment 4-fold and resulted in a more uniform response to variations in rate of application. An antagonism between Embark and 2,4-D amine was observed and avoided by using a lithium salt formulation of 2,4-D in combination with K-104 additive. Therefore, at the end of 1977, it appeared that a useful retardant mixture had been developed.

The critical question for 1978 was whether or not the retardant mixture would control seed heads especially in fescue. The project was started too late in 1977 to obtain much practical information on seed head formation in fescue. Fescue forms seed heads in late May and early June and treatments must be applied before the middle of May in order to make any evaluations on seed head suppression.

A second critical question to be addressed in 1978 was whether or not full season control of roadside vegetation could be obtained by a single application of a chemical mixture in early spring.

3. Method of approach: Test plots were established in the field under simulated roadside conditions to continue evaluation of approximately five growth retardant materials selected from FY 1977 test results and greenhouse and laboratory studies. Optimum dates of application at a fixed rate were determined from studies initiated approximately every two weeks from late March or early April to about the first week in June. Rate studies to determine the optimum rate of application at a fixed date were initiated in April and May. Emphasis was on evaluation of seed head formation. The final method of choice was to count the number of seed heads in the entire plot, for small plots, or in three 10 ft^2 locations selected at random for larger plots. Results are reported in terms of seed heads/ft^2. Since appearance is determined both by the height and number of seed heads, maximum average seed head height was determined as well (essentially the mean height plus one standard deviation as described on page 14 for grass height).

To evaluate the efficacy of the 3-way retardant-additive-herbicide mixture, roadside demonstration tests were established along I-65 north of Lafayette with the assistance of an industrial cooperator. The plots were 10 ft wide and 30 ft long and the entire test involved about 2 miles of roadside. Details concerning test location and mowing restrictions were coordinated through the ISHC with assistance from Mellinger and Bugh. Applications were with a bicycle-type sprayer providing a 10 ft swath. The sprayer was equipped with Spraying Systems 8004 nozzels delivering 40 gal per acre of spray solution at 40 psi CO_2 pressure. The actual ground speed was between 2.4 and 2.5 mph.

4. Major findings: Results from all rate and date studies with both bluegrass and fescue carried out in 1978 are summarized in Figure 8. These plots were all at the Chaffee Laboratories on the Purdue Campus on a uniform mixed stand of bluegrass and fescue and based, for the most part, on triplicate 3 ft X 3 ft plots. Applications in March, April and May were to unmowed grass. Applications in June, July, August and September were to grass mowed to a height of about 2 inches prior to application.

With both species, but especially with bluegrass, greatest effectiveness was in late April. Effectiveness decreased in June and July as temperatures and day length increased to about July 1 when the treatments were virtually without effect. All measurements were taken approximately one month following time of application. Treatment effectiveness then began to increase with applications in September being approximately equal in effectiveness to those in April.

Greatest effectiveness was with the three-way mixture including 2.5 lb/A Li-2,4-D in addition to the Embark and additive K-104 both at 1 lb/A. There was some variation in the effectiveness of the combination but, on the average, the 3-way mixture was almost twice as effective, pound for pound of Embark, as the Embark alone (Fig. 8).

In terms of seed head suppression in fescue, the only practical dates of application are in late March, April and May. Therefore, in subsequent years, date and rate trials were restricted to these months. Embark is effective applied in the fall of the year. However, some effectiveness of the material is loss over the winter and the material is not effective the following spring as the same amount of material applied in the spring.

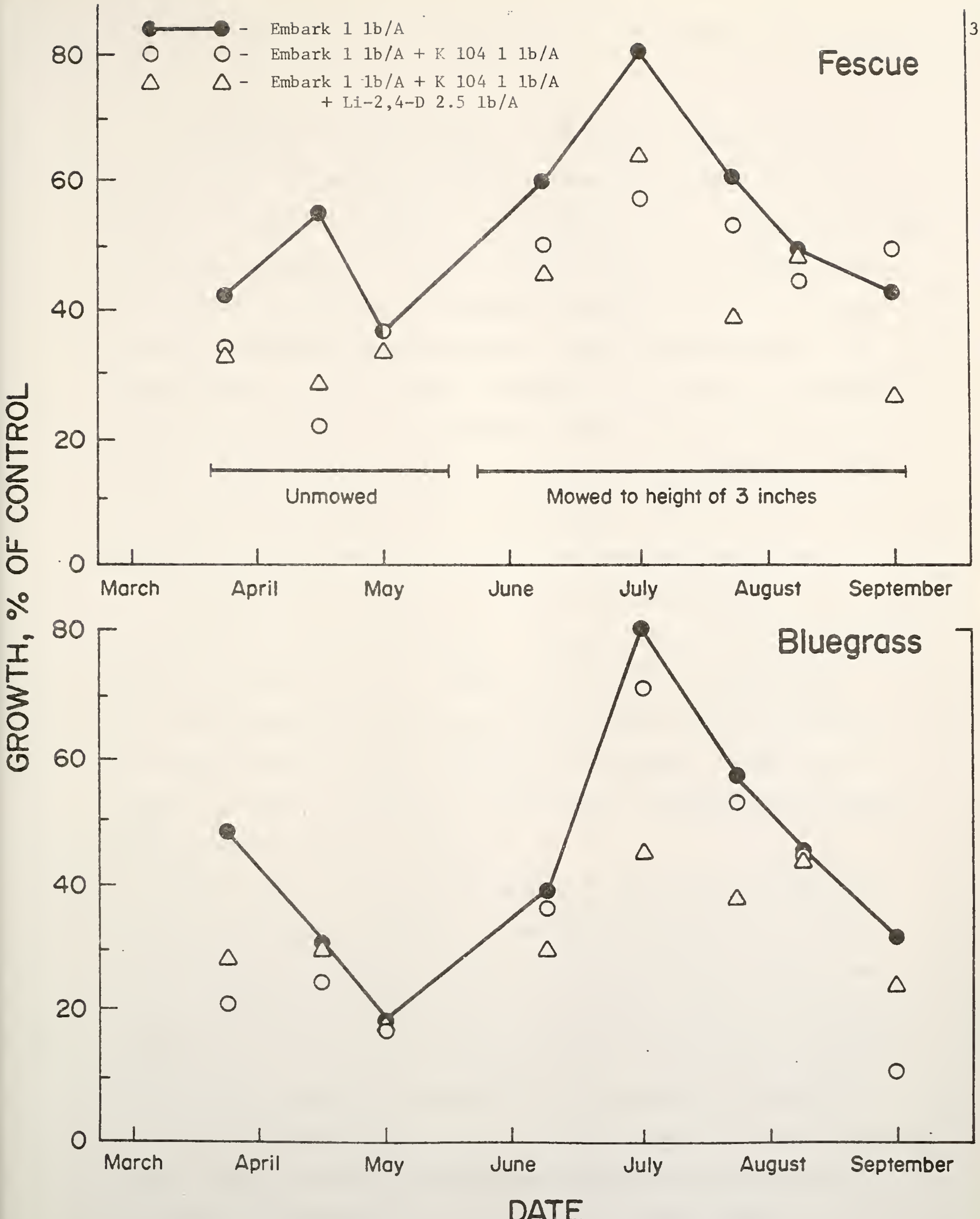

Figure 8. Summary of rate and date studies with Embark (1 lb/A) plus K-104 (1 lb/A) with and without Li-2,4-D (2.5 lb/A) for the 1978 season. Evaluations were approximately 4 weeks after application. Chaffee Laboratories, Tippecanoe County. All rates are given as active ingredients.

As mentioned in the introduction to this section of the report, the critical feature of an effective growth retardant for roadside use is its ability to suppress the formation of seed heads in fescue. This is illustrated in Figure 9 for fescue and bluegrass along I-65 north of Lafayette, Indiana near the White County line. By mid-April, the fescue is about 12 inches high but not objectionable in appearance. Growth proceeds at about 1 inch per week until the end of May when seed heads form. By the end of the first week in June, the grass is now approaching 3 feet in hight due to the seed stalks. By the beginning of August, the seed heads have shattered and only the vegetative parts remain at an average height of about 20 inches. There is almost no further growth of fescue once the seed heads have formed.

Bluegrass shows a similar but not identical pattern (Fig. 9, lower curve). Seed heads form about the same time to a height of about 2 feet and vegetative growth occurs prior to that at a uniform rate of about 1 inch per week. Very little additional growth occurs during the summer months but there is some growth in August followed by die-back in September. Because of the tendancy for blades of bluegrass to "break over," the maximum visual height of bluegrass seldom exceeds 12 inches.

Ideally, what would be required would be a grass growth retardant that prevented completely the formation of seed heads and slowed the vegetative development of the fescue by at least 50% or more so that the total visual height of the roadside never exceeded about 16 inches. These data emphasize, also, the need to carry out a timely application. If the fescue is already 14 inches tall at the time of spraying, it may be difficult to prevent it from reaching 16 inches by fall. If, on the other hand, the fescue is only 6 inches high at the time of spraying, the chances are much better that the the height will be maintained full season at less than 16 inches.

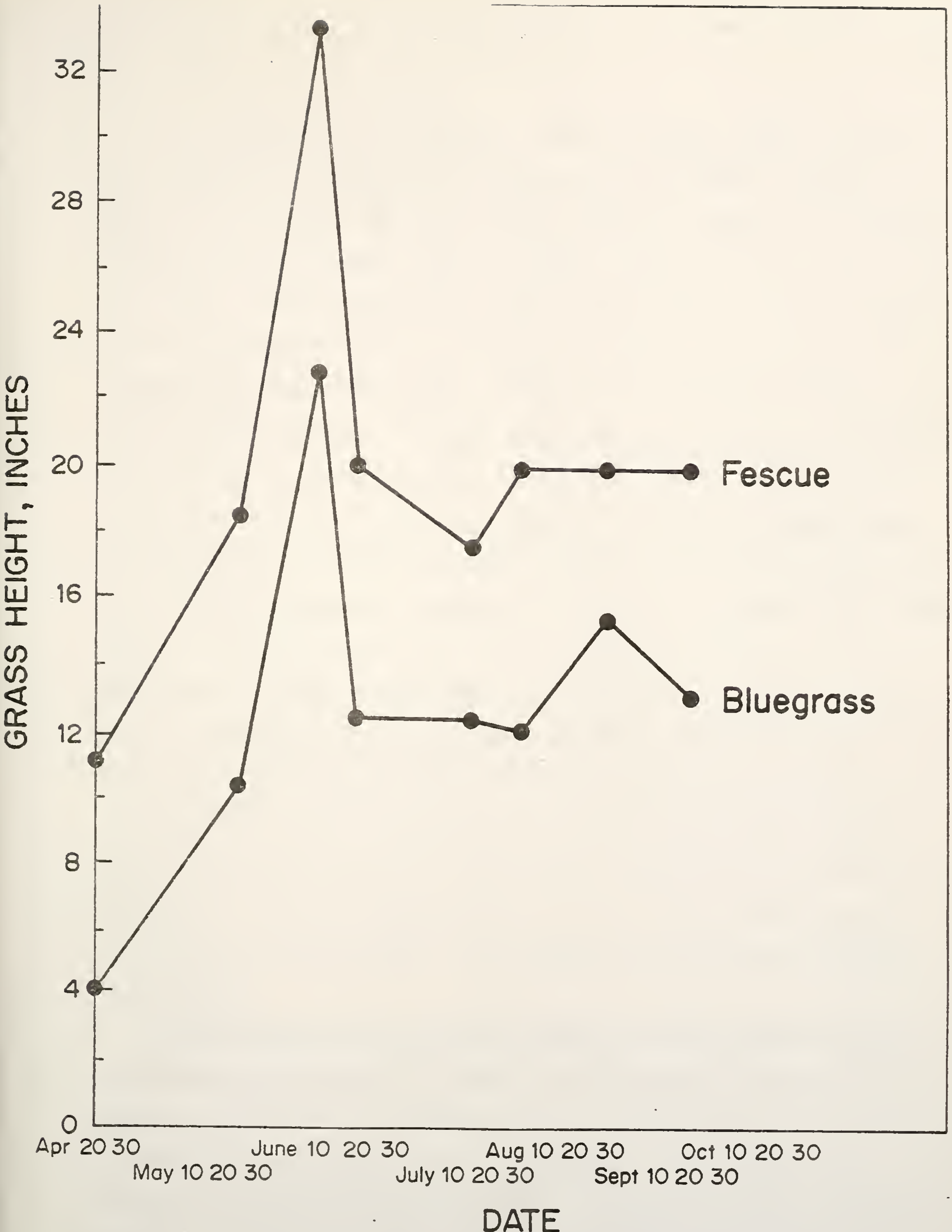

Figure 9. Comparison of grass height as a function of date for unmowed tall fescue and bluegrass. I-65 north of Lafayette, IN. 1978 growing season.

The efficacy of the 3-way mixture of Embark + additive K-104 + Li-2,4-D was demonstrated in tests along the Indiana Interstate System in 1978 and again in 1979 and 1980. In all three years a definite synergism was observed between Embark and additive K-104 that greatly increased the effectiveness of the mixture. The rate dependency of K-104 in the mixture is illustrated in Figure 10 for the 1978 season. Too much or too little in the combination resulted in decreased effectiveness. There was a broad optimum between a ratio of 2 parts K-104 to 1 part Embark and 0.25 parts K-104 and 1 part Embark (all on an active ingredient basis) where the combination was approximately two times as effective in reducing the number of seed heads as Embark alone. The desirability of reducing the amount of K-104 in the mixture was indicated.

The 1978 findings were reproduced in 1979 (Figs. 11 and 12). Results show the rate of K-104 selected initially to be approximately correct but that lower rates could also be used effectively especially on bluegrass (See Fig. 11, 1/2 lb/A Embark). Also, the mixture of Embark plus K-104 (1/2 lb/A of Embark as mefluidide) plus 1/4 lb/A of K-104 was approximately equivalent to 1 lb/A of Embark alone. This was also the lowest effective dose of Embark in the combination resulting in nearly complete suppression of seed heads in fescue (Fig. 12) and in bluegrass (Fig. 11). As a rule, the additive just about doubled the effectiveness of the Embark in the mixture at all rates of Embark tested.

Maximum grass height (average grass height plus one standard deviation) in 1978 was maintained under 16 inches by all combinations of at least ½ lb/A Embark (as mefluidide) plus additive (Fig. 13). Embark alone required 1 lb/A to achieve the same result. The data presented were taken on June 1 but the situation changed very little thereafter. Going into the fall, the plots treated with either ½ or 1 lb/A of Embark plus additive looked as even and attractive as adjacent mowed areas.

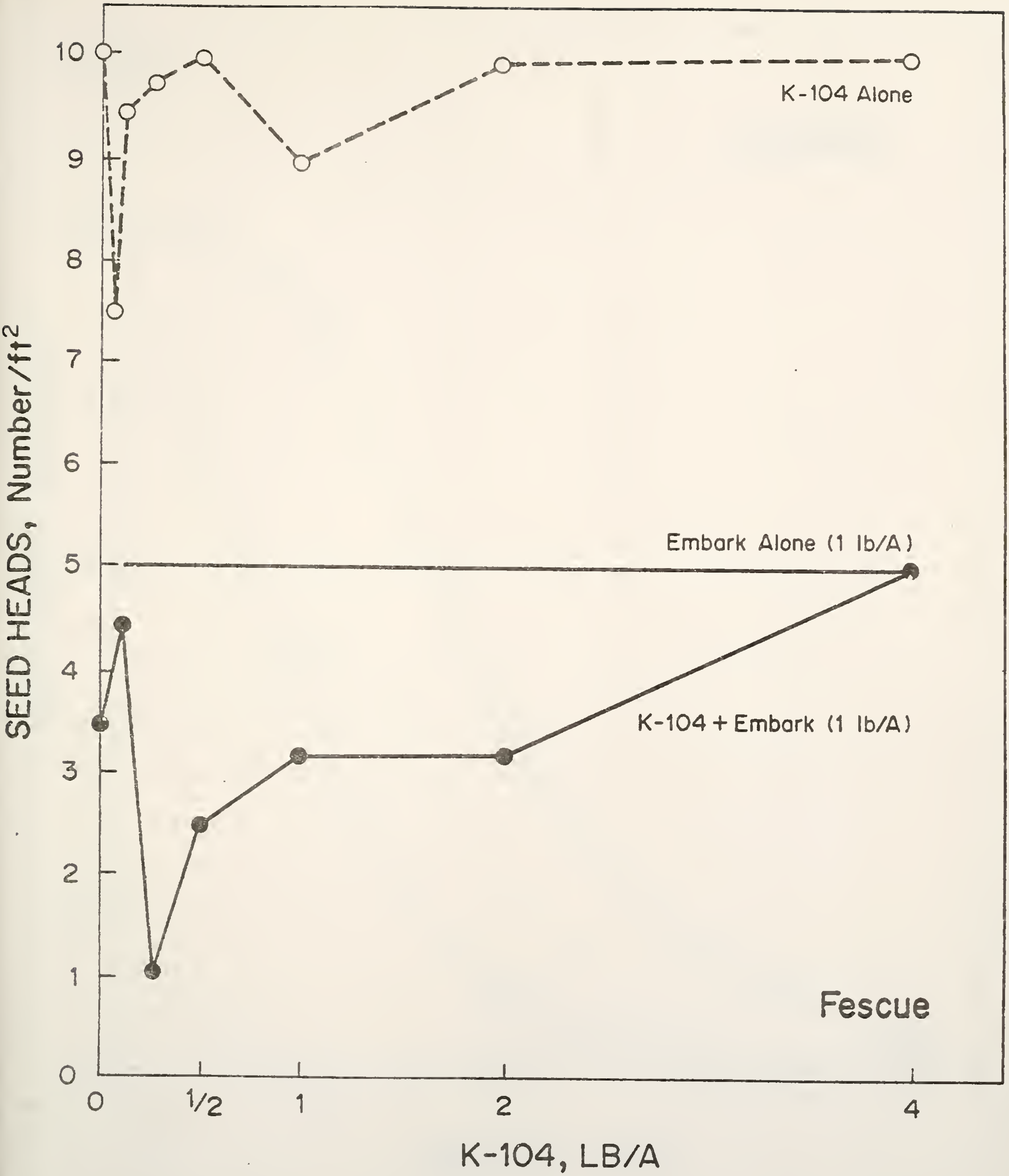

Figure 10. Synergism between varying rates of additive K-104 and Embark (1 lb/A as mefluidide) under roadside conditions. Applications were on I-65S north of Lafayette next to the fence the week of April 20. Each treatment was replicated four times in 10 X 30 ft plots. Evaluations were on June 9, 1978.

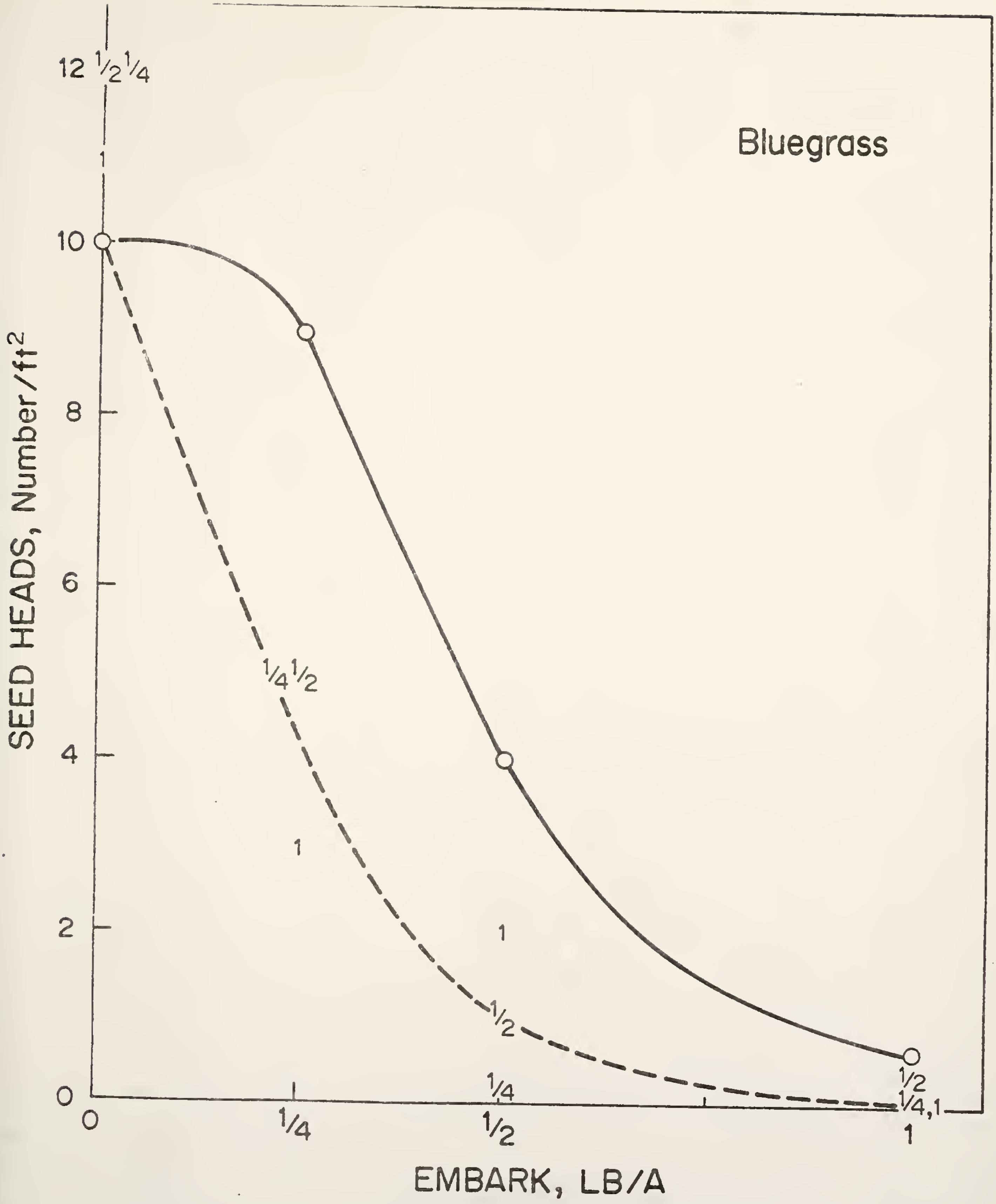

Figure 11. Effect of varying rates of Embark with (1/4. 1/2, 1) and without (0) additive K-104 on seed head suppression in bluegrass. Applications were on April 16 with evaluations on June 1, 1979. Plots were located on I-65 (median) north of Indianapolis. Rates refer to lb/A of active ingredients.

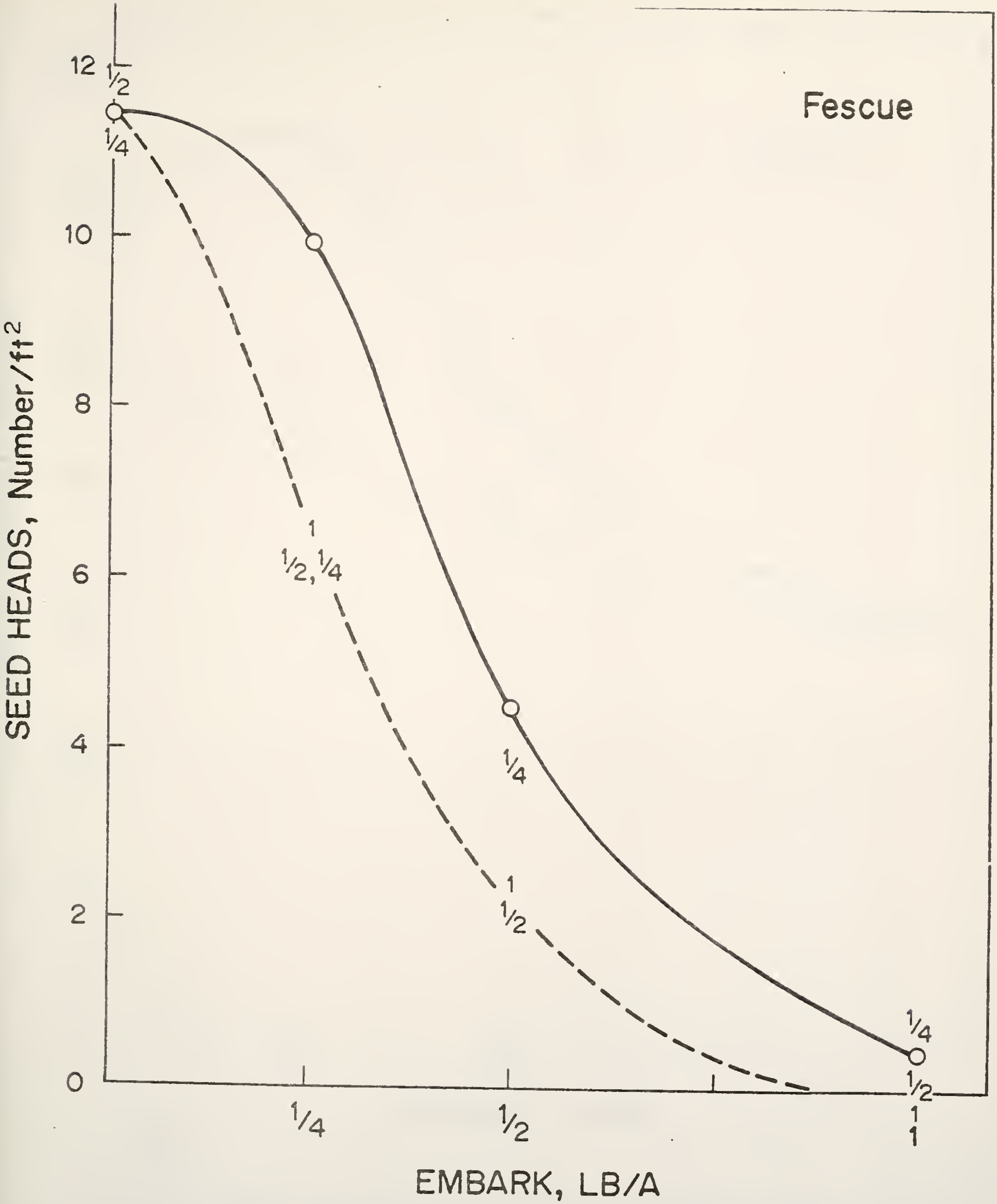

Figure 12. Effect of varying rates of Embark as mefluidide with (¼, ½, 1) and without (0) rates of additive K-104 on seed head suppression in bluegrass. Treatments were applied April 16-17, 1979 adjacent to fence along I-65 north of West Lafayette, IN. Evaluations were on June 1. All rates refer to active ingredient.

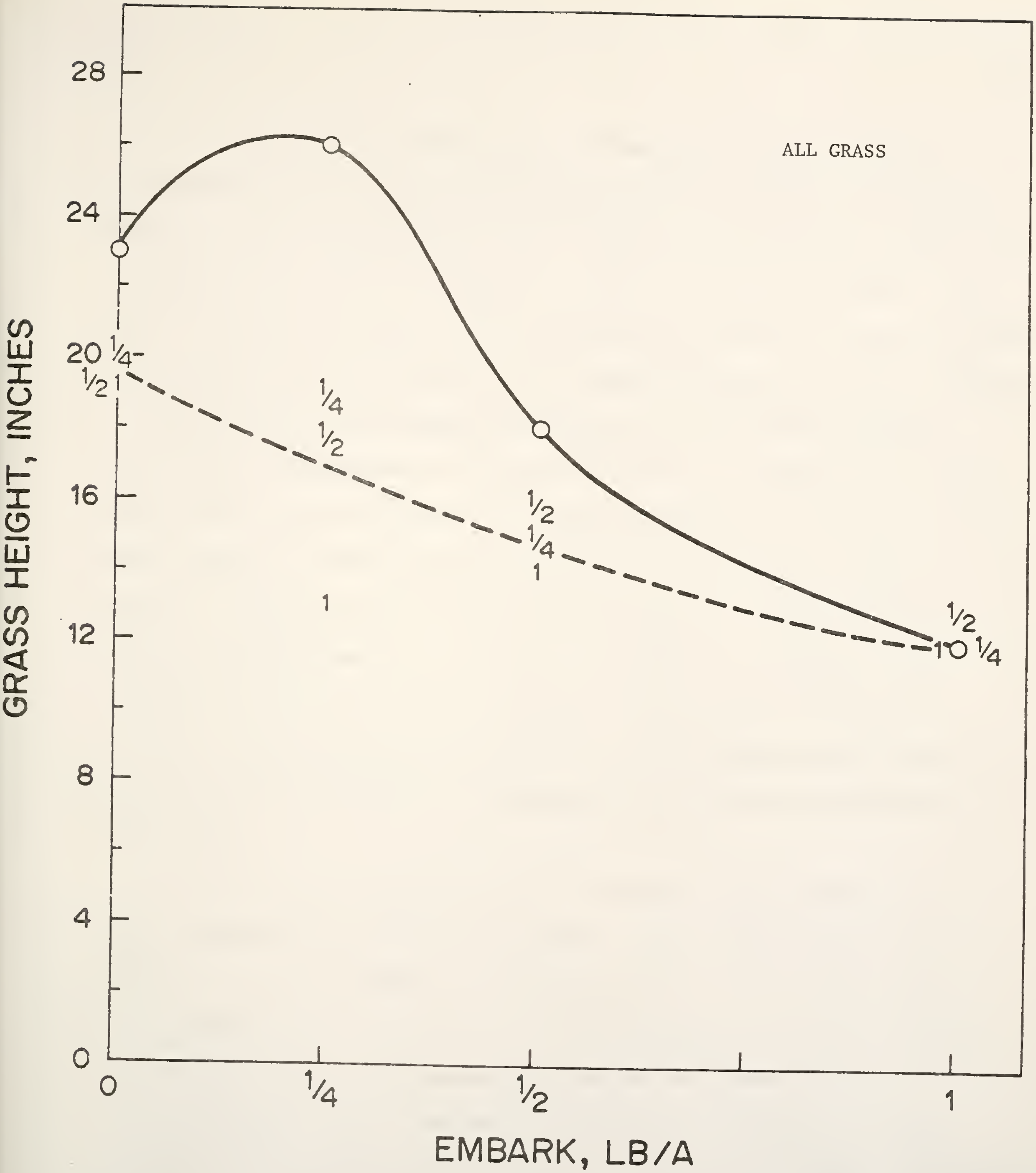

Figure 13. Effect of varying rates of Embark as mefluidide with (¼, ½, 1) and without (0) rates of additive K-104 on seed head suppression in all grass. Treatments were applied April 16-17, 1979 adjacent to fence along I-65 north of West Lafayette, IN. Evaluations were on June 1. All rates refer to active ingredients.

Test results from the 1980 season are summarized in Tables 10 and 11. Applications were at two locations in Marion County, one on the I-65 median and one adjacent to the fence on I-69S. The I-65 application was timely and effective with an April 11 treatment date when the fescue was about 6 inches tall. The I-69S application was on May 2 when the fescue was nearly 18 inches tall and was too late for best results although seed heads were still controlled.

In this test, the recommended maximum rate of application of Embark (0.375 lb/A of mefluidide) was included as well as a treatment at half that rate (0.1875 lb/A of mefluidide). Neither was effective in suppressing seed head formation in fescue with our without the K-104 additive although, as before, the additive doubled the effectiveness of the Embark (Table 10). The best treatment was the one originally selected for testing of 1 lb/A of Embark (actually 1.125 lb/A as mefluidide) plus 1 lb/A of K-104 plus 2.5 lb/A of Li-2,4-D (Table 10, Table 11). This treatment gave virtually no seed heads for the April 11 treatment for fescue and none for bluegrass (Table 10).

Based on these trials and the cost of Embark, it was recommended that a new combination be tested in the spring of 1981. This combination was to consist of ½ lb/A of Embark (as mefluidide) plus 1 lb/A of K-104 (or less, if necessary) and 2.5 lb/A of Li-2,4-D (acid equivalent). The ½ lb/A rate of mefluidide, the active ingredient of Embark, was judged to be the minimum effective rate to suppress the formation of seed heads in fescue and the lowest possible rate of application that could be feasibly implemented. It is clear from the findings that even with the additive, 1 lb/A of mefluidide would be better but too costly for general roadside use if substantial cost savings are to be realized.

Table 10. Summary of Results from an Efficacy Evaluation Test Applied on April 11, 1980 Along I-65 between 82nd Street Overpass and County Road 42 Bridge North of Indianapolis to the Median. Evaluations reported were on June 12, 1980.

Rate, lbs/A of active material			Tall Fescue		Bluegrass	
Embark	K-104	Li-2,4-D	Height (In)	Seed Heads (No./ft^2)	Height (In)	Seed Heads (No./ft^2)
0	0	0	37	18-30	16-22	8 (5-10)
0.1875	0	0	28	12	15	8
0.375	0	0	15-26	10	11	8
0.75	0	0	14	4	10	4
1.125	0	0	11 (13)	1	4	0
0.1875	1	0	20	12	10	2
0.375	1	0	14	4	8	1
1.125	1	0	11	1	6	0
0.1875	1	2.5	19	4	9	3
0.375	1	2.5	15	4	9	3
1.125	1	2.5	10	less than 1	8	0
0	1	0	37	16	18	6
0	1	2.5	38	14	16	10
0	0	2.5	37	18	18	12

Table 11. Summary of Results from an Efficacy Evaluation Test Applied on May 2, 1980 Along I-69S Adjacent to Fence Between Cumberland Road Overpass and 119th Street, Fishers Exit Ramp Sign East of Indianapolis. Evaluations reported were made on June 9, 1980.

Rate, lbs/A of active material			Tall Fescue		Bluegrass	
Embark	K-104	Li-2,4-D	Height (In)	Seed Heads (No./ft^2)	Height (In)	Seed Heads (No./ft^2)
0	0	0	26-33	14-16	12-22	3
0.1875	0	0	24	10	11	4
0.375	0	0	21	4-10	9	0
0.75	0	0	18	3	-	0
0	1	0	33	10	11	1
0.1875	1	0	24	6	-	0
0.375	1	0	20	1	6	0
0.75	1	0	22	6	10	0
0.75	1	2.5	20	3	7	0

This particular application was made too late in the season to be very effective. The fescue was nearly 18 inches tall at the time of application and seed heads were already starting to form. There was very little bluegrass in plots so that only 3 seed heads per ft^2 were observed in the control plots.

In another series of tests, the efficacy of 2,4-D Amine in the control of broadleaf weeds by pre-emergence and direct action following a spring application was verified (Table 12). Additionally, the effectiveness of a spring application of 2,4-D amine in the control of annual grasses by pre-emergence action was also confirmed (Table 13).

Weed counts taken June 12, 1980, approximately 3 weeks after spraying showed 100% control of dandelion, buckhorn plantain, common plantain, speedwell and germinating annuals such as knot weed (Table 12). These data illustrate the rationale of recommending 2.5 lb/A of 2,4-D for the spring application and in the growth retardant combination. At rates of 2 lb/A of 2,4-D and above, 2,4-D Amine is very effective as a pre-emergence herbicide, killing weed seedlings as they germinate.

The only weed species present and not controlled by the spring application was wild carrot. The application was already too late on April 21 to be effective on wild carrot which germinates mostly in the fall and very early spring. Wild carrot is most effectively controlled by 2,4-D Amine as a fall application.

At rates of 2 lb/A of 2,4-D and above, 2,4-D Amine can be very effective as a pre-emergence herbicide controlling not only broad-leaf weeds but annual grasses as well (Table 13). The treatment was judged to have been at least 85% effective for this purpose. Earlier data on giant foxtail demonstrate that this annual grass species is also controlled by an early 2,4-D amine application to about the same extent as yellow foxtail.

For 2,4-D to be effective as a pre-emergence herbicide for control of annual grasses, it must be applied before the grasses germinate but not so soon before that the herbicide has already decomposed when the grasses do finally germinate. Approximately one to two weeks before germination seems to be satisfactory although just before germination is better. Only the shallow germinating grasses are controlled. The seedlings not controlled

Table 12. Control or Roadside Weeds by a Spring Application of 2,4-D Amine. The test was in Tippecanoe County along Indiana 126, a road segment not in the fall-spring spraying rotation by contract. The treatment was applied on April 21, 1980 (2.5 lb/A) and final evaluations reported were on June 12, 1980.

	Weeds/10 ft^2		
Species	Before Spraying	After Spraying	% Control
Dandelion	11	0	100
Plantain	30	0.1	99
Speedwell	28	0	100
Germinating annuals	88	0	100
Wild carrot	28	8	70
Other weeds	2	0.5	82

Table 13. Control of Annual Grasses by a Spring Application of 2.5 lb/A 2,4-D Amine. The test was in Tippecanoe County along Indiana 126, a road segment not in the fall-spring spraying rotation by contract. The treatment was applied on April 21, 1980 and final evaluations reported were in October.

	Weeds/10 ft^2		
Species	Unsprayed Check	Sprayed	% Control
Crabgrass	13 $\pm$ 14	2 $\pm$ 3	85
Yellow foxtail	10 $\pm$ 2	1 $\pm$ 2	90
Goosegrass	3 $\pm$ 3	0 $\pm$ 0	100

The control achieved in these experiments is through a pre-emergence action of the herbicide. These and other grasses are susceptible to 2,4-D only as the seeds germinate in the soil at or near the surface. Therefore, the material must be applied in advance of seed germination. Young seedlings or even seeds germinating deep in the soil below the 2,4-D layer will escape.

seem to be entirely the result of seeds deeper in the soil. Apparently by germinating deep, the seedlings develop sufficient resistance by the time they reach the 2,4-D that they are able to escape.

5. Research Implementation: The first implementation activities were discussed at a meeting of the advisory committee for the project on July 2, 1980. At that time we had 3 years experience with the mixture of Embark + K-104 + Li-2,4-D and Mr. Bugh indicated a willingness at that time to consider treating about 7,000 acres of Interstate median and shoulder to ditch. At that time it was costing $28-30 per acre per mowing cycle to mow. A decision was finally reached at that meeting to treat approximately 100 acres in the Greenfield district using district equipment under the direction of Clyde Mason in the spring of 1981 if materials could be secured in time.

In the summer and fall of 1980, considerable effort was directed toward implementation. Numerous conferences were held with representatives of Velsicol Chemical Corporation, Chicago, IL to supply the K-104 for the tests. These were terminated on October 22 in a meeting in Chicago with Dr. John C. Tapas, Director of Product Acquisitions, Dr. Louis C. Nickell, Vice President, Research and Development, Mr. Walther Matheny, Product Manager, Marketing, Mr. Thomas Delugas, Director of Agricultural Sales, and Mr. Charles Middleton, National Sales Service Director, all of Velsicol Chemical Corporation. At that meeting it was agreed by Velsicol to manufacture and sell, essentially at cost, the required material.

On October 28, 1980, a meeting was held with Messrs. Lucas, Mellinger and Bugh of the Indiana State Highway Commission in Indianapolis concerning the possible use of the three-way growth retardant combination for the spring of 1981. The suggested mixture was ½ lb/A of Embark (as mefluidide), 1/16 lb/A of K-104 plus 2.2 lb/A of Li-2,4-D (available commercially as Lithate). A cost of approximately $65/A was quoted based on information provided by manufacturers and was regarded as break-even since the mowing costs on the roads to be treated were about $25/cycle for three-cycle mowing. With the retardant mixture discussed, we would expect full season vegetation control through a single spray application and with no need for additional herbicide application or mechanical mowing.

At the October 28 meeting concerns were also expressed regarding the need for registration. This matter was pursued with Mr. Methany and Mr. M. O. Messerschmidt, Manager, Product Registration, both of Velsicol. Mr. Messerschmidt contacted L. O. Nelson, Office of the Indiana State Chemist, regarding the use of the material K-104 in combination with Embark and Lithate on a limited basis in 1981. Mr. Nelson ruled that since the product (K-104) was not a pesticide (nor claimed to be a pesticide), it would not require clearance before use. Also in a letter received on November 4, Mr. Messerschmidt indicated that a label for K-104 was being developed by Velsicol (Experimental Number VEL 1001) to identify the product and specify use directions and appropriate precautions (if any). This label would not have required Indiana or EPA clearance and would expected in time for the spring applications. Therefore, at the time of the Quarterly Report of Progress for the period ending December 31, 1980, all appeared to be in readiness for the first year of implementation of the three-way growth retardant mixture into the vegetation management program of the Indiana State Highway Commission. This would have been in accordance with the original schedule for completion of the project.

In January and February of 1980, the Embark was secured from 3-M Corporation, the manufacturer, and Lithate from the Guth Corporation. Unfortunately, also in February, we were informed by Velsicol Chemical Corporation that for them to supply K-104, the cost would be approximately $1000 per pound or $62.50 per acre, even at the projected application rate of only 1/16 lb/A. This would have approximately doubled the material costs from those originally estimated and the decision was made to follow one of two courses of action: 1) Attempt to find a last minute substitute for K-104, and 2) To proceed with the treatment as a 2-way mixture without the K-104.

Various attempts were made in late February and early March to develop a suitable aternative to K-104. The lack of time was a serious factor and the final decision was to apply the original mixture without the K-104 to I-465 around Indianapolis (medians, banks behind guard rails and interchanges). The application was scheduled for the second week of April.

Unfortunately, the recommended rate of ½ lb/A of Embark (as mefluidide) was not applied. Rather, the average rate of application was the recommended label rate of about 3/8 lb/A. At this rate of application, and without the additive K-104, seed head suppression on fescue was no better than 50% and the results were disappointing to say the least (Table 14). A difference between Li-2,4-D and 2,4-D amine was seen at the lowest rates of application but the benefits of the Li-2,4-D did not appear to justify the additional cost (Li-2,4-D turned out to be approximately 4 times more expensive than 2,4-D Amine).

The decision in 1981 was to attempt to find an alternative to K-104, hopefully in time for the spring of 1982. If not, the best course of action seemed to be to continue with the 2,4-D Amine for control of broad-leaf weeds but increase the amount of Embark to the point where a consistent, good job would be expected based upon experimental (1/2 to 3/4 lb/A of mefluidide) rather than label recommendations. The manufacturers of Embark (3M Corporation) were advised of this and a modification of label recommendations was requested for this purpose.

Table 14. Evaluation of an Implementation Test Applied in the Spring of 1981 to I-465 around Indianapolis. The application was under the direction of Clyde Mason, Greenfield District, using State equipment and crews. Observations reported were on May 14, 1981.

Treatment and Rate (lbs/Acre)*			Grass Height (inches)		Seed Heads (No./ft^2)	
Embark	2,4-D Amine	Li-2,4-D	Fescue	Bluegrass	Fescue	Bluegrass
None	None	None	17 ± 2	12 ± 2	18 ± 2	4 ± 2
	Treatments applied on April 15, 1981					
0.375 **	1.5	None	14 ± 2	12 ± 2	16 ± 2	1 ± 1
0.5	2.0	None	10 ± 1	7 ± 1	4 ± 1	2 ± 1
1.0	4.0	None	9 ± 1	5 ± 1	0 ± 0	less than 1
0.375 **	None	1.5	9 ± 1	6 ± 1	1 ± 1	less than 1
0.5	None	2.0	9 ± 1	4 ± 2	5 ± 1	less than 1
	Treatments applied on April 23, 1981					
0.375 **	None	1.5	11 ± 2	9 ± 2	8 ± 3	2 ± 1
	Treatments applied on April 25, 1981					
0.5	None	2.0	14 ± 3	10 ± 2	10 ± 3	3 ± 1

Note: These applications were made without the use of any additive.

* Refer to rates per acre of active ingredient (mefluidide for Embark; 2,4-D acid equivalent for 2,4-D amine and Li-2,4-D)

** Recommended label rate (maximum) for application of Embark.

6. Summary: A treatment consisting of Embark (1 lb/A as mefluidide) plus the additive K-104 (1 lb/A) and the lithium salt of 2,4-D (Li-2,4-D, 2.5 lb/A) was shown to be completely effective in the suppression of seed heads in fescue and bluegrass under roadside conditions. The findings based on three years experience (1978, 1979 and 1980) are illustrated diagramatically in Figure 14. Note that at the 1 lb/A rate of Embark (as mefluidide), in the presence of the K-104 additive, the rate of application could be varied by as much as a factor of two with no loss in uniformity of results. In the absence of the additive (solid curve), a two fold variation in seed head suppression would result with a 2-fold variation in application rate.

The above treatment was found to provide full season control of roadside vegetation with a single spray application (vegetative growth of grass, seed heads of both fescue and bluegrass, broad leaf weeds and, through pre-emergence action of the 2,4-D, annual grasses). The efficacy of the 2.5 lb/A rate in pre-emergence control of annual grasses was verified and provides an important aspect of the rationale for using a rate of 2,4-D application this high.

A scheduled implementation of the three-way combination failed due to the unavailability of the K-104 additive at an affordable price.

7. Reports: An Interim Report "Evaluation of Contractual Roadside Maintenance (Mowing and Spraying) 1977-1979. Summary" was prepared and approved.

A summary of mowing evaluations presented at the Transportation Research Board Meeting in Washington, D.C. on January 18, 1978 was published in Volume 674 of the TRANSPORTATION RESEARCH RECORD.

An Interim Report "Evaluation of Available Herbicides and Herbicide Mixtures for Control of Brush and Milkweed Along Roadsides" was completed and submitted for review and acceptance.

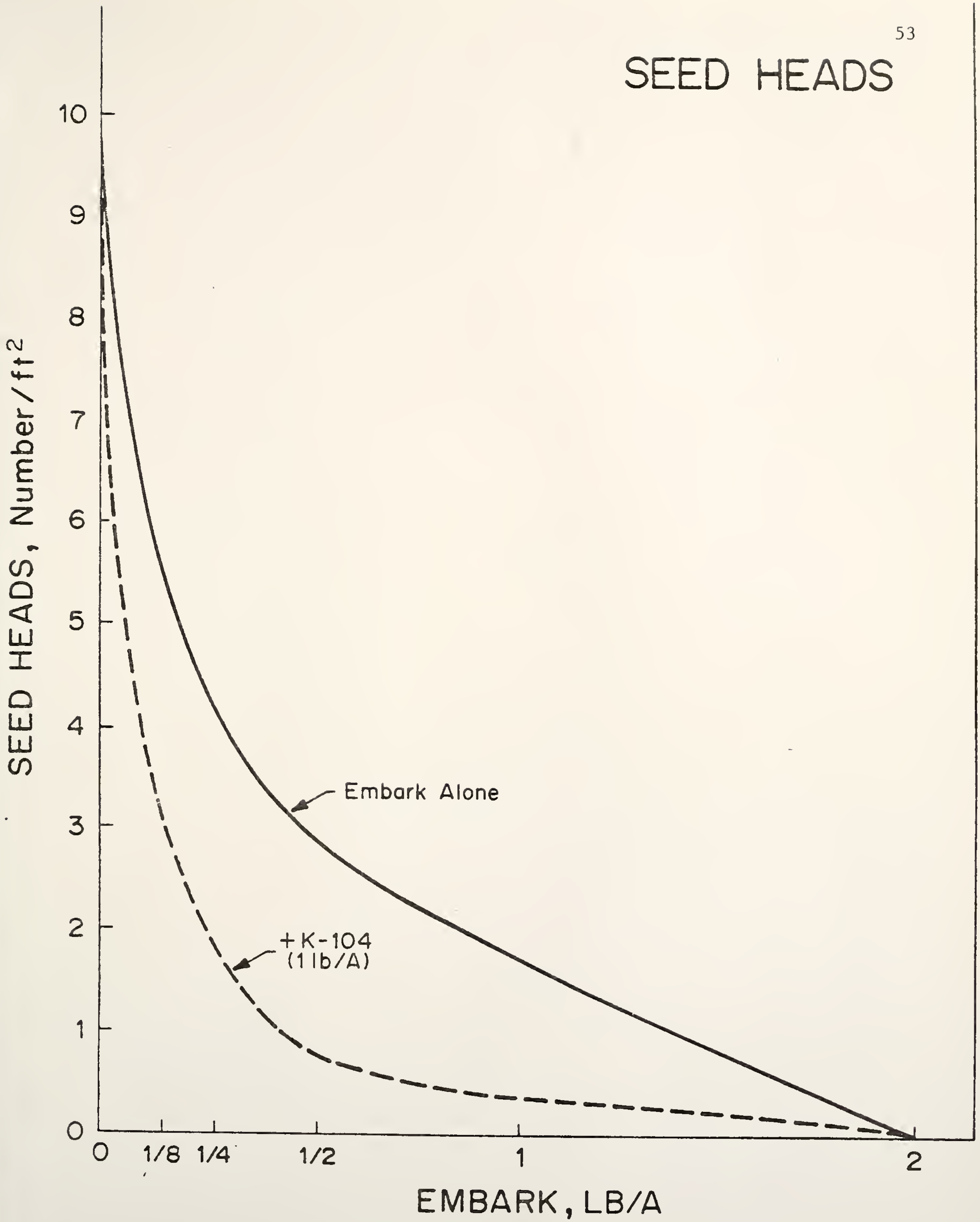

Figure 14. Diagrammatic representation of the dose-response relationship of Embark with (dashed curve) and without (solid curve) additive K-104 on suppression of seed heads in fescue and bluegrass based on three years field experience (1979-1981). The lower, dashed curve shows the effect of 1 lb/A K-104 additive in "flattening" the dose-response curve.

A talk presented at the Transportation Research Board Meeting in San Antonio, Texas and scheduled for publication as part of the proceedings of that meeting was submitted for review. The title of the talk was "Influence of Research and Development on Roadside Management."

A paper "Chemical Mowing" was prepared for presentation at the 67th Annual Purdue Road School Meetings, March 10, 1981, and prepared for publication in the proceedings.

Some of the results of basic studies were presented at the Annual Meeting of the American Society of Plant Physiologists June 15-19, 1981.

P H A S E   I I I

SEARCH FOR NEW SYNERGISTIC ADDITIVES TO ENHANCE EFFICACY OF EMBARK (MEFLUIDIDE)-2,4-D MIXTURES

1981 - 1982

1. Scope and objectives: To identify one or more compounds capable of interacting syngergistically in combination with 2,4-D salts and Embark (mefluidide) to provide cost-effective, single-season, chemical management of roadside vegetation with a single spring application and without mechanical mowing.

2. Introduction: This research phase developed out of necessity rather than design. Previous work, conducted over a period of about 5 years, had demonstrated the efficacy of a 3-way mixture of Embark (mefluidide) plus an additive (K-104) and lithium 2,4-D to give full season control of roadside vegetation following a single spring application. Obtained were complete seed head supression in fescue, elimination of broad leaf weeds (including 2,4-D resistant species) and no injury to bluegrass. Turf was maintained without discoloration and within the mowing limits prescribed by the State of Indiana for the entire growing season without any mechanical mowing. This treatment was schedule for adoption by the Indiana State Highway Commission beginning in the spring of 1981 but was not adopted due to the practical unavailability of the K-104. Therefore, a project was initiated to identify one or more alternatives to K-104 in the mixture for field testing in the spring of 1982 and possible adoption in the spring of 1983.

Because of the nature of the problem, it was necessary to begin essentially from scratch with laboratory and greenhouse trials. It was essential, furthermore, that the new additive be both inexpensive and commercially available. With those two constraints, the search for a new additive was begun.

3. Methods of procedure: Compounds were selected on the basis of known or suspected modes of action of K-104, mefluidide (Embark) and 2,4-D in the original mixture. Initial tests were of compounds applied in aqueous solutions to small turf plots (native bluegrass) on the Purdue University Campus during the summer months of June, July, August and September of 1981. Plots were mowed to a uniform height of about 2 inches one or two days before applying the chemicals. Vegetative growth was monitored by direct measurement of leaf-blade height (average) at weekly or biweekly intervals.

Activity of compounds demonstrating the desired interaction in the field was verified in the laboratory using two tests responsive to mefluidide:

1) the etiolated wheat internode assay (wheat test)

2) the lettuce hypocotyl elongation assay (lettuce test).

In the wheat test, seeds were sprouted in the dark on moistened filter paper sheets in a humid chamber. When the coleoptiles were between 2 and 2.5 cm long (leaf rolls about 0.5 cm from the tip) sections 1 cm long were cut with the coleoptilar node in the center of the section. Sections were floated in the test solutions prepared in distilled water and growth was measured after 18 h.

The lettuce test procedure was that suggested by Dr. K. J. Tautvydas of 3-M Corporation. Seeds of lettuce, var. Grand Rapids, 10 per vial, were growth for 4 days in upright screw-cap glass vials (2.6 X 5.7 cm) containing 0.3 ml of solution to be tested. The vials were placed in a pan with a small amount of water and covered with a transparent polyethylene bag to retain moisture but to allow for gas exchange. The temperature was 25^{o}C with a photoperiod of 15 h provided by Sylvania cool white fluorescent tubes. An average of 15 hypocotyl lengths was measured for each treatment. Hypocotyls were taken to be the stem length between the transition zone and the attachment points of the cotyledons. The transition zone was demarcated by dipping the roots in 1% (w/v) aqueous methylene blue which stains the root only to the transition zone.

4. Major findings: Between June 1 and September 30, 1981, a total of 22 field experiments were conducted involving 291 different treatment combinations, to identify compounds or combinations of compounds with modes of action similar to that of K-104. Two compounds of related chemical structure, designated As IN-IIA and IN-IIB were selected for more extensive testing.

Composite test results from several field trials in small plots demonstrated enhancement of suppression of vegetative growth of bluegrass by Embark and IN-II (Fig. 15). Embark alone gave a steep dose-response curve with a maximum growth inhibition of about 50% at 3/4 lb/A. With these same rates of Embark but in the presence of 1/4 lb/A of IN-IIB, a parallel curve was obtained but with about 70% inhibition at 3/4 lb/A of Embark. In the presence of 1/2 or 1 lb/A IN-IIB, growth suppression equivalent to 3/4 lb/A of Embark alone was obtained beween 1/4 and 1/2 lb/A of Embark in combination. The IN-II additive at 1/4 lb/A was equivalent to 1/4 lb/A of Embark (as mefluidide); at 1/2 and 1 lb/A the IN-II additive as equivalent to 3/8 lb/A of mefluidide.

A major difference between the results of Fig. 15 with the IN-II series and previous findings with K-104 was that growth inhibitions greater than those maximally obtained with Embark alone were obtained with the mixtures. Thus, no improvement in the margin of safety was obvious. The most favorable combination tested in this regard was in the presence of 1 lb/A IN-IIB where the growth inhibition function tended to "flatten out" between 1/4 and 3/4 lb/A of mefluidide.

We noted no response of grass color to the IN-II additives and no evidence of untoward toxicity or of objectionable discoloration of grass with any of the combinations tested.

The preliminary evaluations of comparing different forms of IN-II did not, in the final analysis, reveal major differences (Table 15). IN-IIB was somewhat more effective and more reproducible but this effect was not

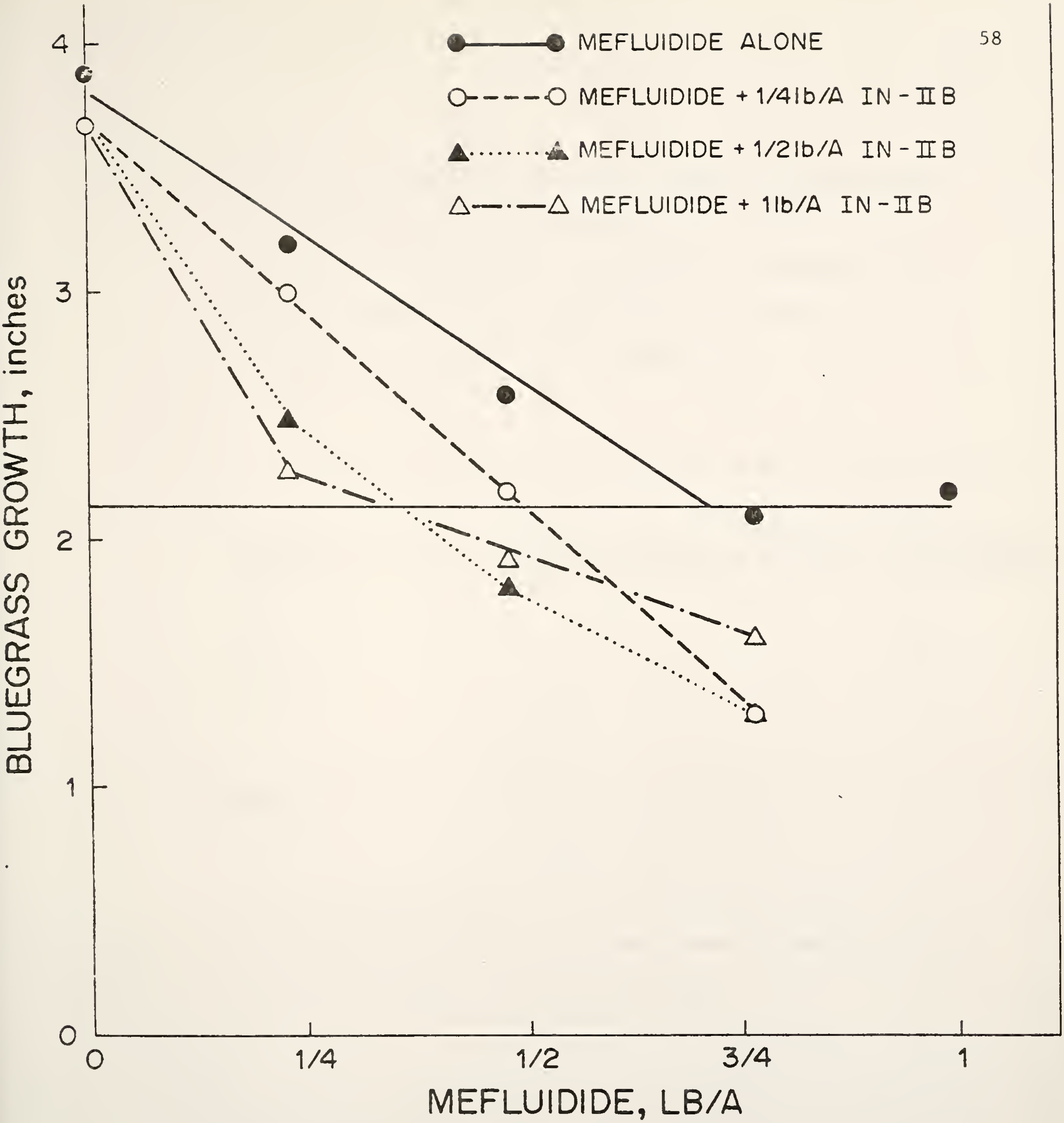

Figure 15. Mean of all dates of application of mefluidide (Embark) at varying rates with and without IN-IIB at 1/4, 1/2 and 1 lb/A on growth of bluegrass truf mowed to a uniform height of about 2 inches prior to spraying. Growth is in inches after about 6 weeks and is corrected for initial height at the time of spraying. Line slopes of treatments plus IN-IIB are significantly different from line slopes of mefluidide (Embark) alone ($p<0.01$).

Table 15. Suppression of vegetative growth of bluegrass by combinations of various forms of IN-II additive at a rate of 1 lb/A with Embark at a rate of ½ lb/A (as mefluidide). Plots were mowed to an initial height of about 2 inches and evaluations were after about 1 month of growth. 1981 growing season.

Additive	Dates of Application	Growth, Percent of Embark Alone
None	All	100
IN-IIA	9/15, 9,18	73 $\pm$ 13
IN-IIB	6/2, 6/10, 6/12, 6/25, 6/29, 7/2, 8/13	73 $\pm$ 20
IN-IIC	6/1, 6/9, 6/10, 6/23, 7/2	77 $\pm$ 40
IN-IID	6/1, 6/10, 6/23, 6/29	78 $\pm$ 30

Plots were not replicated. Individual dates of application were treated as replicates to calculate variance.

statistically significant. The final choice of IN-IIA was based on commercial availability and price.

An apparent synergism between mefluidide and IN-II was verified in laboratory studies. The wheat test yielded a long-linear dose response to both Embark (as mefluidide) and IN-II over the range 10 to 1000 ppm (Fig. 16). These tests were carried out in the presence of 1 ppm of the lithium salt of 2,4-D. An auxin regulator like 2,4-D is required to support sustained growth in this test system. When tested at concentrations of 25 (mefluidide) and 100 (IN-II) ppm, neither compound alone was growth inhibitory (Table 16). However, the combination gave a synergistic growth inhibition of 25%. At 10-fold higher concentrations where both compounds alone inhibited growth by about 25% each, the combination was not only additive but yielded an additional synergism of about 33% so that the final result was a nearly complete inhibition of section growth.

In the lettuce test where the response to mefluidide was log-linear in the concentration range of 0.03 to 1 mg/ml, no clear inhibition due to IN-II was noted over this same concentration range (Fig. 17). Yet, the IN-II was synergistic in its interaction with mefluidide. Results were particularly clear at mixtures of 0.1 mg/ml mefluidide + 0.1 mg/ml IN-II and of 1 mg/ml mefluidide + 1 mg/ml IN-II (marked by an asterisk in Fig. 17).

The findings strongly indicated that the IN-II additives would provide an inexpensive and potentially effective alternative to K-104 for inclusion in 3-way mixture, along with 2,4-D salts and mefluidide, for use in roadside vegetation management. The suggested best rate of application was ½ lb/A Embark (as mefluidide) + 1 lb IN-IIA and 2 to 2.5 lb/A fo 2,4-D Amine per acre. An small advantage of continuing with the lithium salt of 2,4-D did not appear to be justified by the increased cost.

It must be emphasized that efficacy in seed head formation in fescue had not been determined in 1981 nor had the mixture been tested in the field in

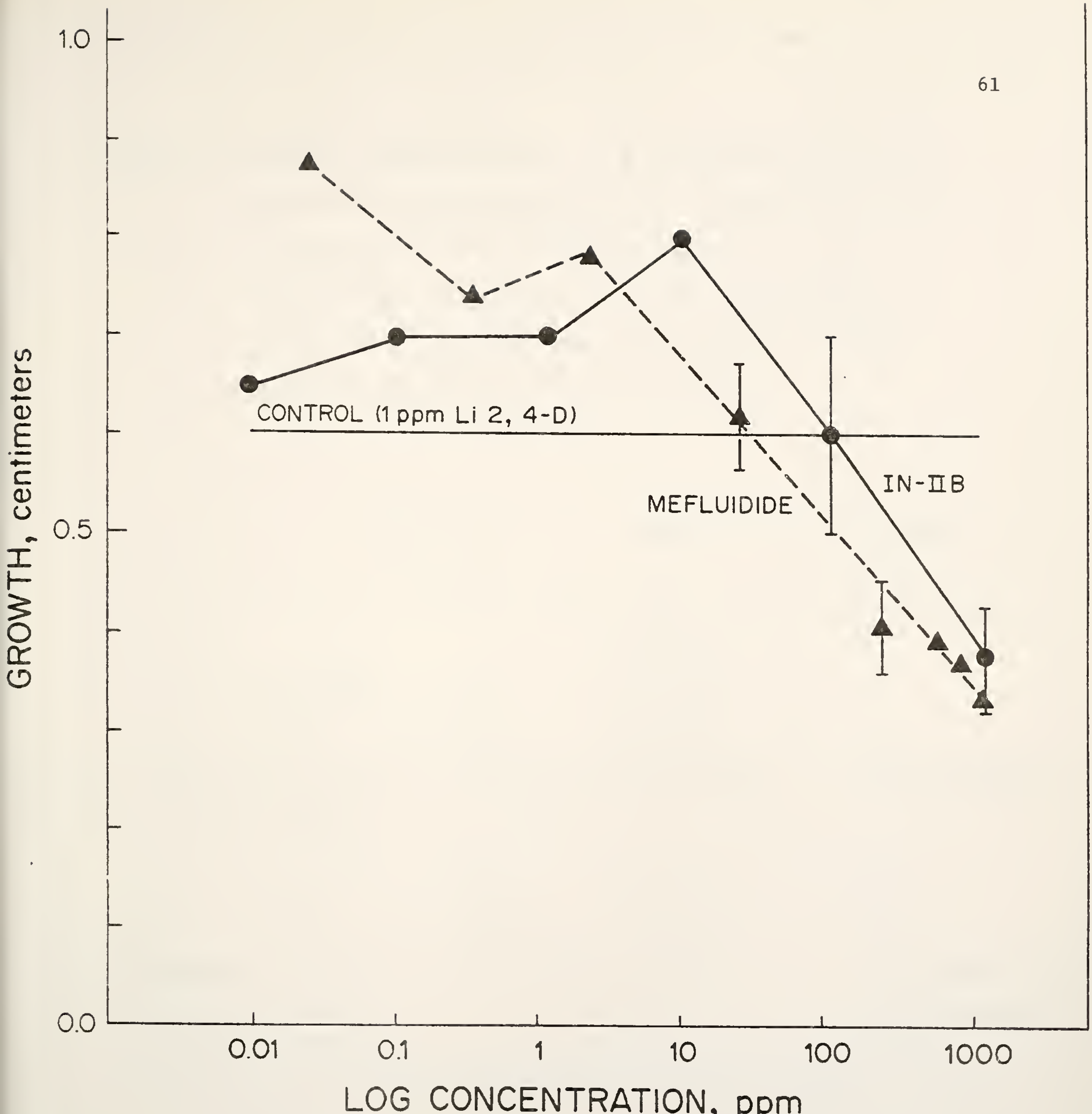

Figure 16. Dose-response relationships of Embark (mefluidide) and IN-IIB alone in the wheat test. All treatments contained 1 ppm 2,4-D to support growth. Values are based on single determinations of triplicate samples of 10 sections each except for concentrations marked by standard deviation bars where 3 to 5 determinations were included.

Table 16. Apparent synergism between IN-IIB and mefluidide (Embark) for inhibition of growth in the wheat test in the presence of the lithium salt of 2,4-D. Growth was measured after about 16 h. Each experiment consisted of triplicate determinations of 10 sections each. Each experiment was replicated three times. Standard deviations are between experiments.

Treatment	Concentrations, ppm	Growth, cm	Growth inhibition, cm
Li-2,4-D	1	0.6 ± 0.10	0
Li-2,4-D + mefluidide	1 + 25	0.6 ± 0.10	0
Li-2,4-D + IN-IIB	1 + 100	0.6 ± 0.10	0
Combination (Li-2,4-D + mefluidide + IN-IIB)	1 + 25 + 100	0.45 ± 0.005	0.15 (synergism)
Li-2,4-D + mefluidide	1 + 250	0.4 ± 0.17	0.2
Li-2,4-D + IN-IIB	1 + 1000	0.43 ± 0.11	0.17
Combination (Li-2,4-D + mefluidide + IN-IIB)	1 + 250 + 1000	0.03 ± 0.07	0.37 (additive + 0.20 synergism)

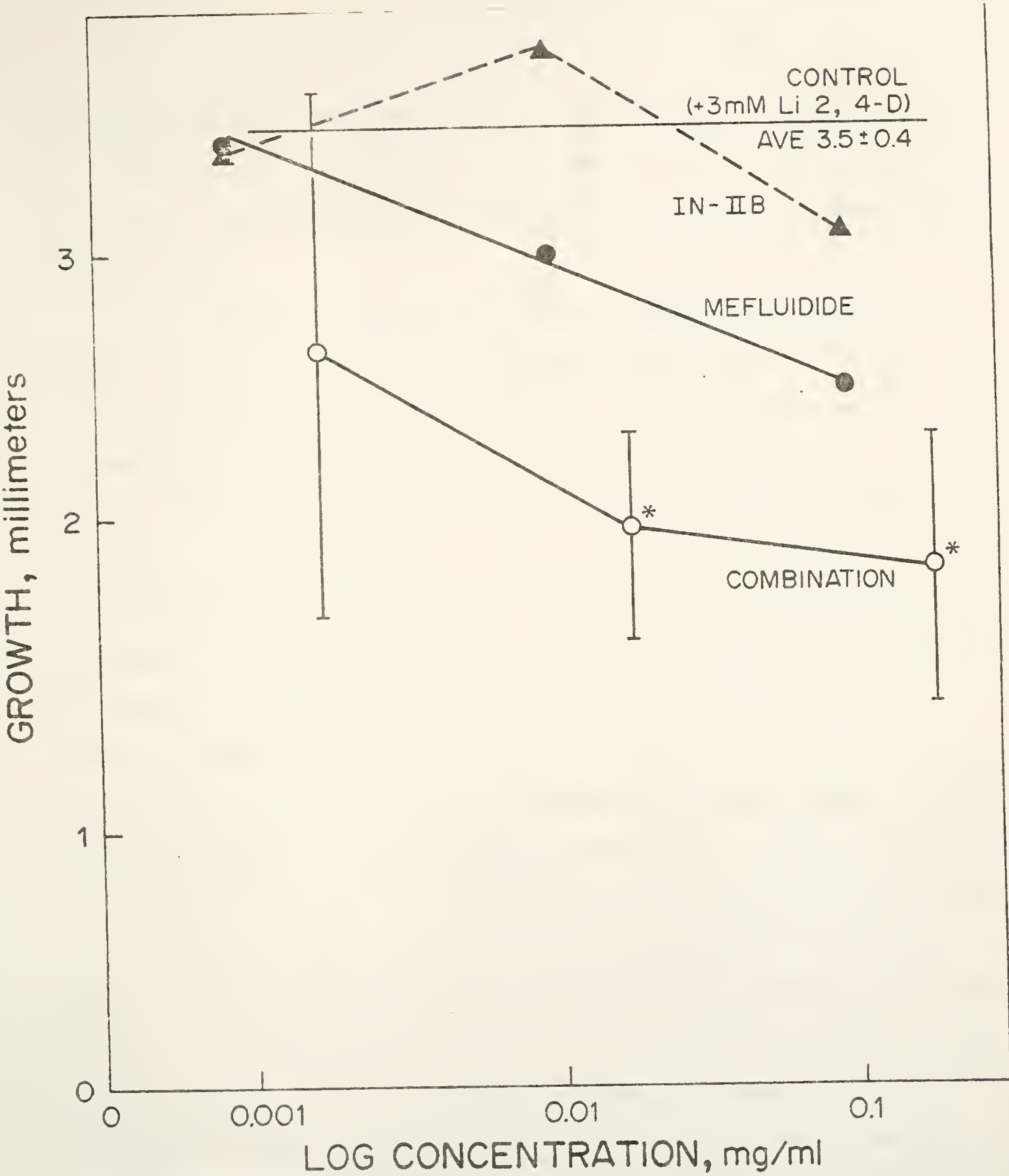

Figure 17. Apparent synergism between IN-IIB and mefluidide in the lettuce hypocotyl test. All compounds were tested in the presence of 3 mM Li-2,4-D. The combination is equal parts of IN-IIB and mefluidide. Values marked by an asterisk are significantly different ($p < 0.01$) from 2,4-D alone.

combination with the herbicide 2,4-D. A priority objective for the spring of 1982 then was to test the IN-II compounds for efficacy in suppression of seed heads in fescue and whether or not anatagonsim with 2,4-D Amine would pose a problem.

A major advantage of IN-II was its cost. Estmates made in 1981 place the technical grade material at about $3.00 per pound for IN-IIA. Since interactions were obtained as low as 0.5 lb/A, the extra cost of the additive would be as little as $1.50 per acre and equivalent to ½ lb/A of Embark costing about $26.00 with a net cost savings of $24.50 per acre in costs of materials.

The ability of IN-IIA to interact with Embark to increase efficacy in suppression of seed head formation was quickly confirmed in early tests on bluegrass in the field in 1982 (Table 17). In the absence of 2,4-D Amine, the optimum amount of IN-IIA to combine with ¼ lb/A of Embark was 1/2 lb/A (Table 18). At ½ lb/A of Embark, the optimum amount of IN-IIA was nearer to 1 lb/A. The differences between ½ and 1 lb/A of IN-IIA in the presence of ½ lb/A of Embark were small and not statistically significant just as observed the previous fall with grass growth (Fig. 15). Similar results were obtained with seed head suppression in fescue (Fig. 18). Clearly the optimum for IN-IIA in the presence of ½ lb/A Embark appeared to be nearer 1 lb/A or higher. It was also becoming apparent that amounts of IN-IIA substantially higher or lower than that required to give the optimum ratio could be detrimental to the action of the Embark (Fig. 18). Therefore, it appeared that the ratio of IN-IIA to Embark was the critical feature rather than the absolute amount of IN-IIA and that the approximate optimum ratio of IN-IIA to Embark in the absence of 2,4-D Amine was 2:1. This was confirmed in subsequent roadside tests with seedhead formation in both fescue and bluegrass (Fig. 19). At four different rates of Embark application (1/8, ¼, ½ and 1 lb/A as mefluidide), the addition of an amount of IN-IIA twice that of

Table 17. Effect of Embark With and Without Additive IN-IIA on Early Seedhead Formation of Bluegrass. Treatments were applied April 13, 1982. Final data were collected on May 4, approximately three weeks after treatment. Results are an average of four replicate plots ± standard deviations.

Treatment	Rate, Lbs/A*	Seed Heads/Ft^2	Range
Control	-	48 ± 5	43-54
IN-IIA	1	43 ± 9	32-52
Embark	½	18 ± 3	15-22
Embark + IN-IIA	½ + 1	5 ± 6	0-10

*Active ingredient.

Table 18. Effect of Embark plus IN-IIA Additive on Numbers and Heights of Seed Heads of Native Bluegrass in the Field. Applications were on April 21, 1982. Evaluations were on May 12, 1982. Greenhouse area, Purdue University, Lafayette Campus. Results are combined from 3 to 4 replications from two experiments.

Treatment, lb/A			Average Seed Head
Embark*	IN-IIA	Seed Heads, No./Ft^2	Height, Inches
0	0	40 ± 6	13.9 ± 4.2
¼	0	28 ± 18	10.1 ± 0.6
¼	1/10	27 ± 14	10.9 + 1.1
¼	1/2	18 ± 8	9.4 ± 0.9
¼	1	30 ± 8	11.4 ± 1.1
¼	10	40 ± 10	11.1 ± 1.4
½	0	27 ± 8	10.3 ± 0.8
½	1/10	29 ± 12	9.9 ± 0.5
½	1/2	14 ± 9	9.3 ± 1.2
½	1	13 ± 9	8.4 ± 2.6
½	10	18 ± 2	10.5 ± 1.5

* As mefluidide.

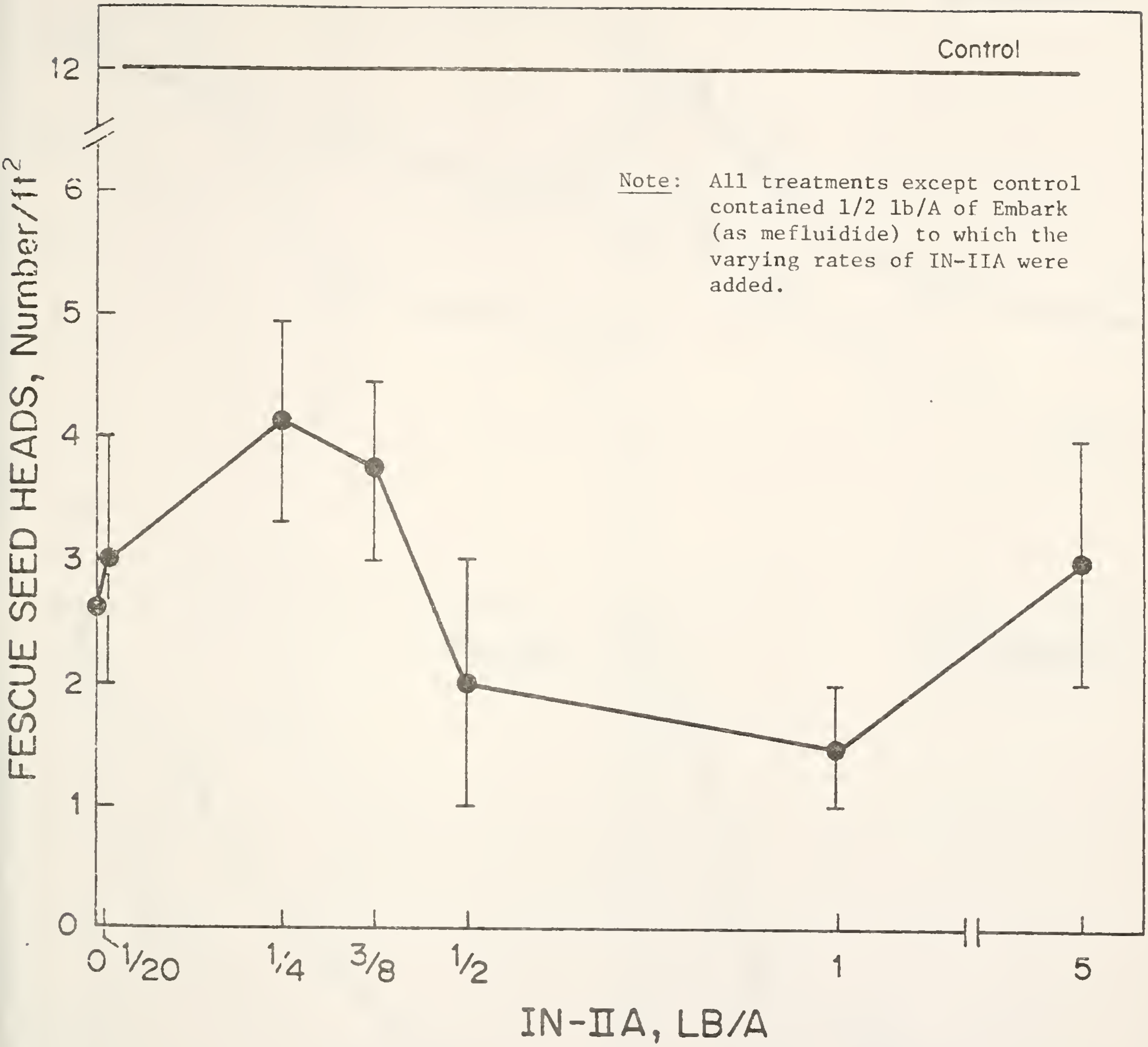

Figure 18. The influence of varying rates of IN-IIA on seedhead suppression in fescue by 1/2 lb/A of Embark (as mefluidide). Treatments were applied April 18, 1982. Observations reported were on May 15 approximately 1 month after treatment. The grass height at the time of treatment was 6.5 inches.

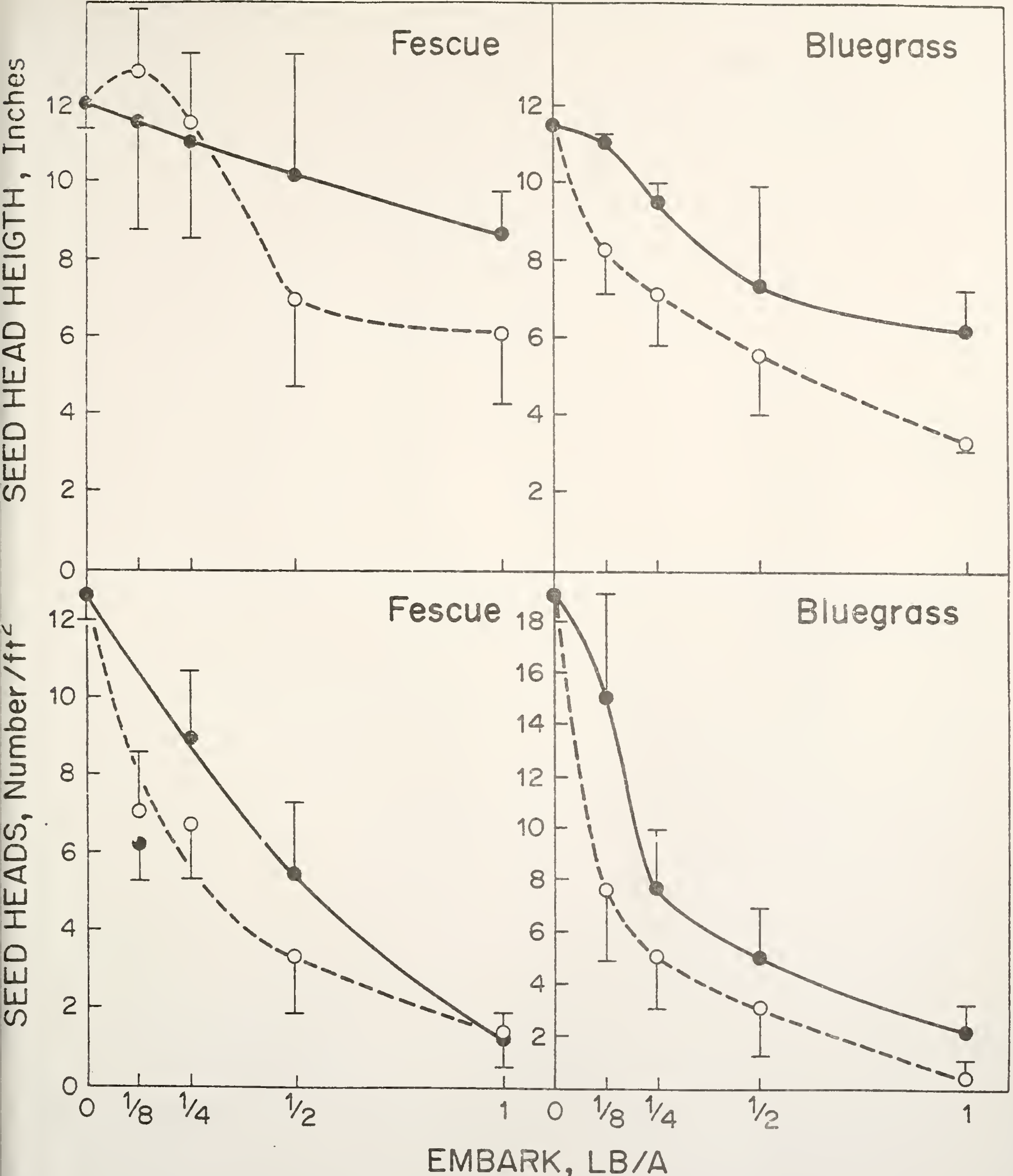

Figure 19. Effect of Embark (lb/A as mefluidide) plus IN-IIA additive on height and number of seedheads in fescue and bluegrass under roadside conditions. Applications were along IN 126 in Lafayette, IN on April 27, 1982. Evaluations were on May 15, 1982. Values are averages of three replicates ± standard deviations. Solid curve = Embark alone. Dashed curve = Embark plus an amount of IN-IIA twice that of the Embark.

the amount of Embark approximately doubled the efficacy of the Embark in the mixture for suppression of seedhead formation in both fescue and bluegrass (Fig. 19, lower two panels) and, except for the lowest rates of application for fescue, in the suppression of seed stalk elongation (Fig. 19, upper two panels).

Unfortunately, a compromise rate between 1/2 and 1 lb/A of 3/4 lb/A of IN-IIA had been selected the previous fall for mixing with ½ lb/A of Embark based on information available at that time. This rate of IN-IIA in the mixture did not perform badly with Embark alone in the field (Tables 19 and 27) but broke down completely when the 2 lb/A of 2,4-D Amine required for control of broad leaf weeds was added (Tables 19-21, 23-27). The extreme antagonism between 2,4-D and the IN-IIA-Embark interaction was seen even in a reduction in the ability of the 2,4-D Amine to control broad leaf weeds (Table 20). The number of red clover (the dominant broad leaf species in this test) heads formed in the presence of IN-IIA and Embark + 2,4-D Amine was approximately 3 times the number formed in the absence of IN-IIA with only Embark and 2,4-D Amine present (Table 20).

The 2,4-D Amine - IN-IIA antagonism was corrected simply by increasing the amount of IN-IIA in the mixture (Fig. 20, Table 21). For suppression of fescue seed head formation, the optimum IN-IIA at ½ lb/A Embark was 1 lb/A IN-IIA. For ¼ lb/A Embark, the optimum was ½ lb/A IN-IIA (Fig. 20). This optimum rate of ½ lb/A of IN-IIA in the presence of ¼ lb/A of Embark was later confirmed in yet another test (Table 22).

It is possible that at ½ lb/A Embark the optimum rate of IN-IIA may be even slightly higher than 1 lb/A. Certainly, the 3/4 lb/A rate of IN-IIA originally selected in the absence of information on the interaction with 2,4-D Amine was a marginally low rate that resulted in inconsistent

Table 19. Comparison of IN-IIA Additive With and Without 2,4-D Amine on Growth and Seedhead Formation in Fescue and Bluegrass. Plots were located along IN 126 in Lafayette, IN. Applications were on April 1, 1982 when the grass was 2 to 3 inches tall.

		Grass Height, Inches		Seed Heads, No./ft^2	
Treatment	Rate/Acre*	Bluegrass	Fescue	Bluegrass	Fescue
None		11 ± 1	25 ± 1	19 ± 1	42 ± 7
Embark	½	7 ± 0	19 ± 2	10 ± 6	20 ± 2
Embark + IN-IIA	½ + 3/4	7 ± 0	14 ± 0	6 ± 5	9 ± 1
Embark + IN-IIA + 2,4-D Amine	½ + 3/4 + 2	7 ± 0	23 ± 1	7 ± 7	26 ± 7

* Rates given in pounds of active ingredient.

Evaluations reported were on May 23, 1982, approximately two months after treatment.

Table 20. Comparison of IN-IIA Additive With and Without 2,4-D Amine on Growth and Seedhead Formation in Fescue and Bluegrass and Removal of Red Clover, the Major Broadleaf Species Present. Plots were located along IN 126 in Lafayette, IN. Applications were on April 1, 1982 when the grass was 4½ inches tall. Evaluations reported were on June 5, two months after treatment.

		Height, Inches			Seed Heads, No./ft^2		
Treatment	Rate/Acre	Bluegrass	Fescue	Red Clover	Bluegrass	Fescue	Red Clover
None		14.6±2.5	33.7±0.5	21.2±1.8	4.2±1.6	21.5±2.6	15.5±1.7
Embark	½	17.6±3.4	31.6±1.8	21.3±1.2	1.7±0.7	11.0±1.7	12.4±1.4
Embark + IN-IIA	½ + 3/4	15.0±1.3	30.4±2.1	20.0±1.7	2.4±0.2	10.2±1.7	11.2±1.1
Embark + 2,4-D Amine	½ + 2	10.5±0.7	25.3±1.9	14.0±4.6	1.5±0.7	4.4±1.0	2.1±2.6
Embark + IN-IIA + 2,4-D Amine	½ + 3/4 + 2	12.7±1.0	27.2±1.5	14.0±4.6	2.2±0.5	5.2±4.4	7.6±4.2

All rates of materials are in pounds per acre of active ingredient.

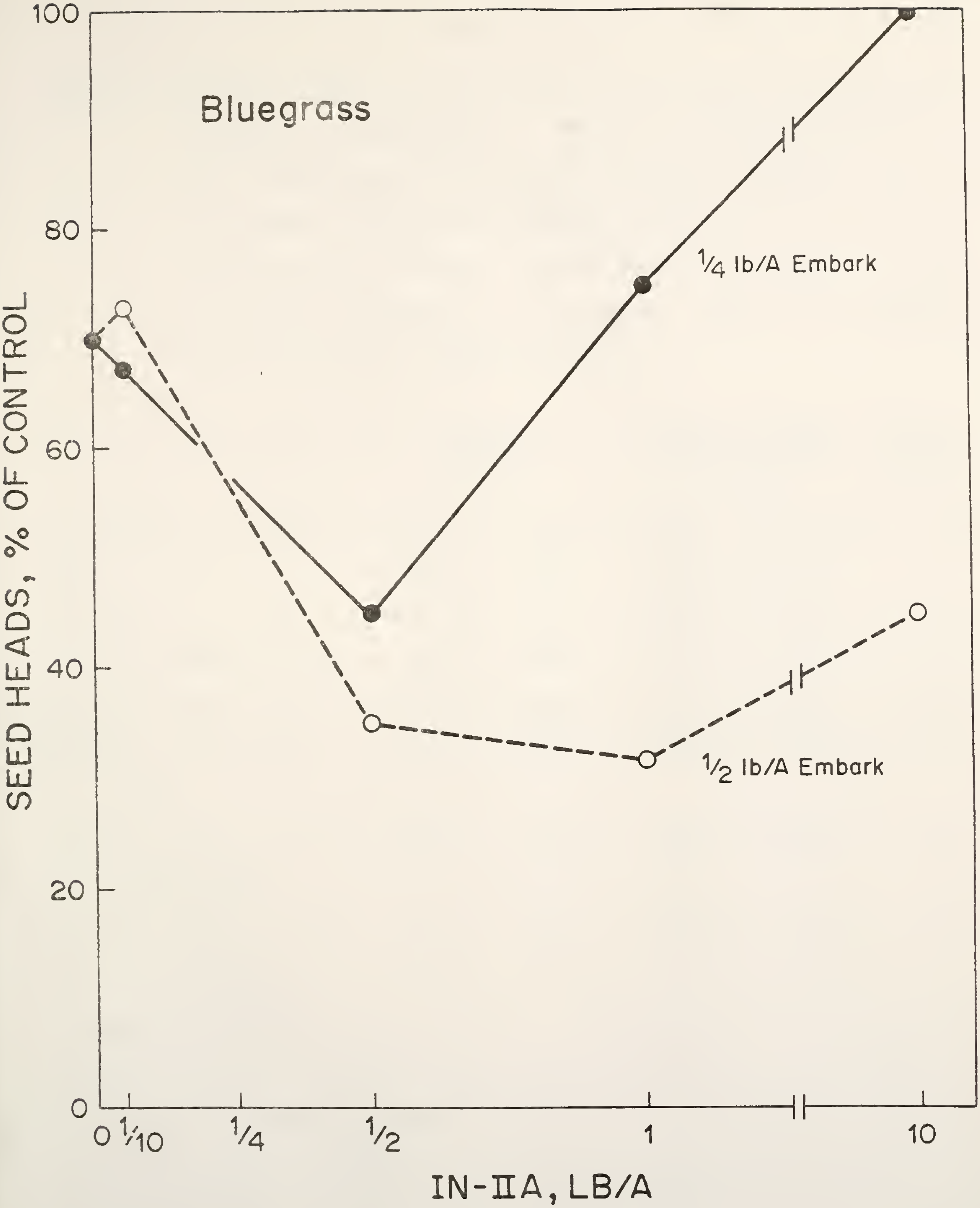

Figure 20. Effect of varying rates of IN-IIA in combination with two rates of Embark (1/4 and 1/2 lb/A as mefluidide) plus 2 lb/A 2,4-D amine on seed head formation in bluegrass in the field. Applications were on April 4, 1982. Evaluations were on May 12, 1982.

Table 21. Effect of Embark With and Without IN-IIA on Height and Numbers of Seedheads and Antagonism by 2,4-D Amine. Applications were on May 5, 1982 along IN 126, Lafayette, Indiana. Evaluations are an average of observations taken May 31 and June 10. Weed control information was on August 6. Fescue was 12 inches high at the time of spraying; bluegrass was 7 inches high. Values are averages from three replicates $\pm$ standard deviations.

		Seed Heads (No./ft^2)		Seed head height (inches)		Total weeds
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass	No./10 ft^2
None		16.9$\pm$5.0	3.3$\pm$1.3	39.0$\pm$3.0	22.8$\pm$3.8	2.9
Embark	½	7.5$\pm$3.9	1.5$\pm$0.2	28.6$\pm$5.2	14.7$\pm$1.7	4.0
Embark + IN-IIA	½ + 1	3.3$\pm$0.6	2.2$\pm$0.5	25.6$\pm$2.1	21.0$\pm$4.0	3.1
Embark + IN-IIA	½ + 5	9.3$\pm$2.8	2.8$\pm$2.2	32.0$\pm$7.3	18.2$\pm$3.5	2.2
Embark + 2,4-D Amine	½ + 2	8.2$\pm$4.4	1.9$\pm$1.3	30.0$\pm$4.3	17.6$\pm$3.3	0.6
Embark + IN-IIA + 2,4-D Amine	½ + 1 + 2	8.2$\pm$2.7	1.8$\pm$1.9	29.4$\pm$1.2	16.6$\pm$1.9	1.1
Embark + IN-IIA + 2,4-D Amine	½ + 5 + 2	8.0$\pm$2.4	1.3$\pm$1.2	30.9$\pm$1.9	17.2$\pm$3.0	0.0
Average minus 2,4-D						3.3
Average plus 2,4-D						0.6
% Control of broad leaf weeds						90

Active ingredient.

Table 22. Late Experiment to Verify the Proper Ratio of Additive IN-IIA to Embark at ¼ lb/A of Embark. Plots were located adjacent to IN-126 in West Lafayette, IN. Applications were on May 12, 1982. Evaluations were on June 6. Each treatment was replicated three times.

		Seed Heads per ft^2		Seed Head Height, Inches**	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None	-	23.1 ± 5.0	4.0 ± 4.0	40.2 ± 3.7	25.3 ± 4.6
Embark	¼	18.4 ± 2.9	2.5 ± 2.0	29.0 ± 3.0	14.3 ± 4.6
Embark + IN-IIA	¼ + 1/8	17.7 ± 3.2	2.3 ± 0.6	30.9 ± 6.0	15.3 ± 1.2
	¼ + ¼	16.4 ± 4.0	2.2 ± 1.3	31.6 ± 3.9	12.8 ± 0.4
	¼ + ½	10.7 ± 4.7	1.9 ± 1.4	24.2 ± 7.0	13.8 ± 2.3
	¼ + 1	14.3 ± 0.9	3.2 ± 3.2	31.2 ± 4.1	21.1 ± 0.8

* Lbs per acre of active ingredient.

** Initial height at the time of treatment was 11 inches for fescue.

performance of the IN-IIA additive when applied in the presence of 2,4-D Amine (Tables 23-27). At the higher rates of IN-IIA not only was the performance in seed head suppression restored in the presence of Embark and 2,4-D Amine, but also the ability of the 2,4-D Amine to achieve effective control of broad leaf weeds (Table 21).

While the rates and ratios of IN-IIA were being adjusted, a second additive designated XM-12S was introduced into the field testing program. XM-12S was given to us by 3-M Corporation as a result of their greenhouse program to seek additives to enhance the effectiveness of Embark and to reduce the 2,4-D-Embark antagonism.

XM-12S turned out to be a very effective additive (Tables 23-27). For example with a timely application in early to mid April, the combination of ½ lb/A Embark (as mefluidide) + 1% (by volume in the total spray mixture) XM-12S + 2 lb/A 2,4-D Amine (acid equivalent) gave 83% (Table 23) and 85% (Table 25) suppression of seed heads in fescue and 98% suppression of seed heads in bluegrass (Tables 23 and 25). The fescue seed heads that formed were less than 15 inches in length at the 2 lb/A rate of 2,4-D Amine and less than 8 inches in length for bluegrass (Table 25). Blade height for fescue was 7 (Table 26) to 10 (Table 24) inches and for bluegrass was 5 inches or less (Tables 24 and 26). These results were under Interstate conditions.

Similar results were obtained on an interchange in another location on an interchange. Here, the fescue is less robust than adjacent to the pavement or along the fence and better performance may be achieved at lower Embark rates (Table 27). Never-the-less, the XM-12S additive continued to to perform well. On the interchange, 94% suppression of seed heads in fescue was achieved by Embark at 3/8 lb/A plus 1% XM-12S and 2 lb/A 2,4-D Amine (Table 27). These applications were on April 27 which was acceptible for the interchange but not for the roadsides proper (Table 28). Fescue on the

Table 23. Comparison of Additives IN-IIA and XM-12S on Seedhead Formation of Fescue and Bluegrass. Plots were located in the median of US 52 West of Lafayette, IN, adjacent to golf course east of Wabash River. Applications were on April 12 and April 19, 1982. Evaluations reported were on May 27. Each treatment was replicated three times.

		Seed Heads per ft^2		Seed Head Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None		18.5 ± 4.6	8.1 ± 0.9	26.4 ± 1.5	14.2 ± 2.0
		APPLIED APRIL 12, 1982			
Embark	¼	6.5 ± 3.1	0.2 ± 0.2	22.6 ± 2.9	8.0 ± 1.0
	½	3.9 ± 3.4	0.0 ± 0.0	19.6 ± 1.1	-
Embark + 2,4-D Amine	¼ + 4	7.9 ± 5.6	1.0 ± 1.0	21.9 ± 5.2	10.4 ± 1.3
	½ + 4	4.5 ± 5.8	0.4 ± 0.2	19.7 ± 1.6	10.3 ± 2.1
Embark + IN-IIA +	¼ + 3/4 + 4	5.0 ± 3.0	0.6 ± 0.5	20.1 ± 1.9	7.0 ± 0.0
2,4-D Amine	½ + 3/4 + 4	2.7 ± 2.1	0.0 ± 0.0	20.1 ± 1.0	-
Embark + XM-12S +	¼ + 1% + 4	4.6 ± 2.2	0.1 ± 0.2	18.9 ± 1.6	13.0
2,4-D Amine	½ + 1% + 4	3.1 ± 1.1	0.1 ± 0.2	20.5 ± 2.2	9.0
		APPLIED APRIL 19, 1982			
Embark	¼	13.0 ± 0.6	0.7 ± 0.4	26.0 ± 4.9	9.8 ± 3.2
Embark + 2,4-D Amine	¼ + 2	13.3 ± 2.4	3.8 ± 2.3	25.4 ± 3.7	11.3 ± 1.9
Embark + IN-IIA + 2,4-D Amine	¼ + 3/4 + 2	14.1 ± 8.3	2.5 ± 0.7	25.5 ± 1.4	10.4 ± 0.8
Embark + XM-12S + 2,4-D Amine	¼ + 1% + 2	9.2 ± 5.1	1.1 ± 0.3	22.4 ± 1.0	8.9 ± 0.2

* Lbs per acre of active ingredient except for XM-12S which is given as percent in total mixture.

Table 24. Comparison of Additive IN-IIA and XM-12S on Growth of Fescue and Bluegrass. Plots were located in the median of US 52 west of Lafayette, IN, adjacent to golf course east of Wabash River. Applications were on April 12 and April 19, 1982. Evaluations were on May 20. Each treatment was replicated three times.

Treatment	Lbs/A	Grass Height, Inches Fescue	Bluegrass
None	-	11.0 ± 0.0	7.0 ± 1.7
	Applied April 12, 1982		
Embark	¼	9.0 ± 0.0	4.3 ± 0.8
	½	8.7 ± 0.6	4.8 ± 1.0
Embark + 2,4-D Amine	¼ + 4	11.3 ± 0.6	6.7 ± 0.7
	½ + 4	11.0 ± 0.0	7.0 ± 1.7
Embark + IN-IIA +	¼ + 3/4 + 4	10.0 ± 0.0	4.5 ± 0.5
2,4-D Amine	½ + 3/4 + 4	10.3 ± 1.2	4.3 ± 0.3
Embark + XM-12S +	¼ + 1% + 4	9.0 ± 1.0	5.5 ± 0.9
2,4-D Amine	½ + 1% + 4	10.3 ± 1.5	5.7 ± 0.7
	Applied April 19, 1982		
Embark	¼	11.0 ± 0.0	5.7 ± 1.5
Embark + 2,4-D Amine	¼ + 2	11.7 ± 1.5	7.0 ± 1.0
Embark + IN-IIA + 2,4-D Amine	¼ + 3/4 + 2	10.0 ± 1.0	5.7 ± 0.7
Embark + XM-12S + 2,4-D Amine	¼ + 1% + 2	9.6 ± 0.6	5.3 ± 0.7

* Lbs of active ingredient per acre except for XM-12 which is given in percent by volume in total mixture. Applied by Dan Webel, 3M.

Table 25. Comparison of Additives IN-IIA and XM-12S on Seed Head Formation of Fescue and Bluegrass. Plots were located in the median of US 52 west of Lafayette, IN, near the Purdue University Agronomy Farm. Applications were on April 19, 1982. Evaluations were on May 27. Each treatment was replicated three times.

		Seed Heads per ft^2		Seed Head Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None		26.6 ± 6.9	24.5 ± 9.3	26.2 ± 2.2	14.7 ± 0.9
Embark	¼	15.4 ± 5.3	6.9 ± 1.7	22.6 ± 4.5	11.3 ± 4.4
	3/8	14.9 ± 1.2	3.8 ± 1.4	18.4 ± 1.5	11.5 ± 4.1
	½	6.9 ± 1.3	2.0 ± 1.7	13.5 ± 5.0	4.9 ± 1.7
Embark + 2,4-D	¼ + 2	15.0 ± 4.2	12.8 ± 2.6	20.7 ± 1.3	14.3 ± 0.9
Amine	3/8 + 2	11.0 ± 2.9	9.4 ± 3.1	18.2 ± 2.2	12.6 ± 2.5
	½ + 2	6.8 ± 2.7	5.2 ± 1.1	15.1 ± 2.6	8.6 ± 1.8
Embark + IN-IIA +	¼ + 3/4 + 2	18.7 ± 3.2	13.2 ± 2.5	21.9 ± 3.6	13.2 ± 2.5
2,4-D Amine	3/8 + 3/4 + 2	11.2 ± 0.7	9.1 ± 4.0	21.5 ± 2.1	11.3 ± 1.2
	½ + 3/4 + 2	12.6 ± 9.3	8.6 ± 6.8	17.8 ± 3.4	11.7 ± 1.2
Embark + XM-12S +	¼ + 1% + 2	11.3 ± 4.2	5.0 ± 1.5	16.4 ± 0.2	9.2 ± 3.8
2,4-D Amine	3/8 + 1% + 2	6.8 ± 3.6	1.9 ± 0.7	17.5 ± 1.9	8.7 ± 1.8
	½ + 1% + 2 **	3.8 ± 2.3	0.6 ± 1.0	14.6 ± 2.7	7.2 ± 3.0

* Lbs per acre of active ingredient except for XM-12S which is given in percent in total mixture. Applied by Dan Webel, 3M.

** 86% inhibition of seed head formation if fescue and 98% inhibition in bluegrass. Fescue seed heads that formed were less than 15 inches high. Blade height of fescue was less than 7 inches. Blade height of bluegrass less than 5 inches.

Table 26. Comparison of Additives IN-IIA and XM-12S on Growth of Fescue and Bluegrass. Plots were located in the median of US 52 west of Lafayette, IN, near the Purdue University Agronomy Farm. Applications were on April 19, 1982. Evaluations were on May 20. Each treatment was replicated three times. Applied by Dan Webel, 3M.

		Grass Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass
None		9.0 ± 1.0	7.0 ± 1.0
Embark	¼	6.3 ± 2.3	5.2 ± 0.6
	3/8	7.0 ± 1.0	4.5 ± 1.0
	½	7.3 ± 4.2	4.3 ± 1.2
Embark + 2,4-D Amine	¼ + 2	8.0 ± 0.0	5.0 ± 1.0
	3/8 + 2	8.0 ± 1.0	4.5 ± 0.9
	½ + 2	6.8 ± 0.8	4.3 ± 1.2
Embark + IN-IIA +	¼ + 3/4 + 2	9.3 ± 0.6	6.0 ± 1.0
2,4-D Amine	3/8 + 3/4 + 2	7.0 ± 0.0	5.5 ± 0.5
	½ + 3/4 + 2	6.7 ± 1.2	4.8 ± 1.0
Embark + XM-12S +	¼ + 1% + 2	7.3 ± 0.6	4.3 ± 0.6
2,4-D Amine	3/8 + 1% + 2	7.3 ± 0.6	4.3 ± 0.6
	½ + 1% + 2	6.3 ± 1.2	4.0 ± 0.5

* Lbs per acre of active ingredient except for XM-12S which is given in percent in total mixture.

Table 27. Comparison of Additive IN-IIA and XM-12S on Growth of Fescue and Bluegrass. Plots were located on an interchange on I-70 near Plainfield, IN. Applications were on April 27, 1982. Evaluations were on May 27. Average of three replications.

		Seed Heads per ft^2		Seed Head Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None	-	17.3 ± 3.5	7.8 ± 4.4	30.6 ± 3.7	18.4 ± 1.3
Embark	¼	2.9 ± 1.0	4.6 ± 2.4	21.8 ± 1.2	10.8 ± 2.6
	3/8	4.0 ± 1.3	2.9 ± 0.3	22.5 ± 1.8	13.1 ± 2.8
	½	1.5 ± 0.7	1.2 ± 1.6	17.0 ± 1.7	10.8 ± 1.1
Embark + IN-IIA	¼ + 3/4	1.0 ± 0.6	0.9 ± 0.2	16.8 ± 3.9	10.2 ± 2.3
	3/8 + 3/4	2.3 ± 0.4	0.8 ± 0.4	18.3 ± 1.2	7.6 ± 4.4
	½ + 3/4	1.1 ± 0.7	3.1 ± 2.6	16.7 ± 2.1	10.6 ± 1.9
Embark + IN-IIA +	¼ + 3/4 + 2	9.8 ± 1.9	4.8 ± 1.3	23.6 ± 0.2	14.1 ± 2.2
2,4-D Amine	3/8 + 3/4 + 2	3.6 ± 2.2	2.6 ± 2.2	19.9 ± 3.7	10.3 ± 2.8
Embark + XM-12S	¼ + 1%	1.3 ± 0.9	3.8 ± 1.3	17.0 ± 2.6	8.6 ± 2.3
	3/8 + 1%	1.0 ± 0.3	5.0 ± 3.5	12.6 ± 4.3	9.2 ± 1.7
	½ + 1%	0.0 ± 0.3	1.0 ± 1.2	-	7.9 ± 2.6
Embark + XM-12S +	¼ + 1% + 2	1.4 ± 0.5	2.9 ± 2.4	17.3 ± 4.5	8.0 ± 2.6
2,4-D Amine	3/8 + 1% + 2	1.0 ± 0.6	2.2 ± 2.7	16.3 ± 2.0	8.1 ± 3.2

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture. Applied by Dan Webel, 3M.

Table 28. Lack of Effectiveness of All Treatments Applied May 6, 1982. Plots were located in the median of US 52 West of West Lafayette, IN, near the Purdue University Agronomy Farm. Applications were on May 6, 1982 with evaluations on May 27. Each treatment was replicated three times.

		Seed Heads per ft^2		Seed Head Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None		33.5 ± 1.5	42.0 ± 2.0	24.2 ± 0.2	17.0 ± 0.0
Embark	¼	26.5 ± 11.5	22.2 + 6.2	17.3 ± 4.0	13.6 ± 1.0
	3/8	23.2 ± 8.7	19.5 ± 6.5	18.3 ± 5.3	10.6 ± 0.1
	½	22.0 ± 5.7	26.7 ± 8.0	18.9 ± 4.2	13.5 ± 0.8
Embark + 2,4-D	¼ + 2	30.2 ± 7.2	30.0 + 1.0	19.9 ± 3.2	13.6 ± 2.0
Amine	3/8 + 2	30.7 ± 8.7	31.2 ± 1.5	17.2 ± 1.5	14.0 ± 2.0
	½ + 2	33.5 ± 0.8	35.3 ± 1.5	19.2 ± 1.2	12.3 ± 0.3
Embark + IN-IIA +	¼ + 3/4 + 2	29.3 ± 5.7	33.5 ± 5.5	23.6 ± 2.6	14.7 ± 0.3
2,4-D Amine	3/8 + 3/4 + 2	34.0 ± 2.0	33.3 ± 4.7	21.3 ± 1.3	15.0 ± 0.0
	½ + 3/4 + 2	35.6 ± 8.7	35.8 ± 9.5	21.5 ± 7.5	14.5 ± 0.2
Embark + XM-12S +	¼ + 1% + 2	29.6 ± 11.4	29.2 ± 3.9	17.3 ± 6.0	11.3 ± 1.3
2,4-D Amine	3/8 + 1% + 2	23.8 ± 5.5	25.0 ± 1.4	15.2 ± 1.9	8.5 ± 0.8
	½ + 1% + 2	15.1 ± 3.5	22.8 ± 1.8	14.2 ± 0.8	8.2 ± 9.9

* Lbs per acre of active ingredient except for XM-12 S which is given as percent in total mixture. Applied by Dan Webel, 3M.

Note: In this study, which was applied very late, the bluegrass had already formed seed heads at the time of application and fescue was starting to form seed heads. Fescue was over 12 inches high at the time of treatment and bluegrass was over 8 inches high.

interchanges tends to head out much more sparsely and later than does fescue between the pavement and fence or on the medians. An application on May 6, for example, to the median of US 52 west of West Lafayette, IN in 1982 was totally ineffective even with the additives present. This is because, at the time of application, the bluegrass was already headed out and the fescue was over 12 inches high and also starting to form seed heads. The timeliness of the application must be stressed as an important requirement. In 1982, April 19 was about the latest date, overall, that gave adequate seed head suppression in fescue in the Lafayette area except for selected areas where seed heads were formed later.

When the rate of 2,4-D Amine was varied in the presence of ½ lb/A of Embark plus either 0.5 or 1% MX-12S, greatest effectiveness was found at the higher rates of 2,4-D amine for seed head suppression for fescue but not for bluegrass (Tables 29 and 30). In fact, the combination of 3/8 lb/A of Embark + 1% XM-12S + 3 lb/A 2,4-D Amine, on the interchange situation, resulted in 94% suppression of seed heads and those few seed heads that formed were only about 12 inches high (Table 30). Since both these applications were very late, it is possible that the bluegrass had already begun to form seed heads and these tests need to be repeated earlier in 1983. In any event, the bluegrass seed heads that formed were fairly short and did not create an objectionable appearance.

In the interchange test of Table 30, Banvel (dicamba) at rates of ½, 1 and 1½ lb/A (active material) were applied, also in combination with Embark and the additive XM-12S. An antagonism between Banvel and Embark was seen similar to that between 2,4-D Amine and Embark. Mixing Banvel and Embark did not alter the situation appreciably. As with 2,4-D Amine and Embark, the addition of additive XM-12S reduced or eliminated the

Table 29. Comparison of Different Rates of 2,4-D on the Effectiveness of Embark Alone and in the Presence of Additives IN-IIA and XM-12S. Plots located along IN 126 in Lafayette, IN. Applications were on May 6, 1982. Evaluations reported were on May 26, 1982. Averages of results from three replications ± standard deviations.

Treatment, lbs/A*				Seed Heads per ft^2		Seed Head Height, Inches**	
Embark	IN-IIA	XM-12S	2,4-D Amine	Fescue	Bluegrass	Fescue	Bluegrass
½	0	0.5%	½	8.9 ± 0.5	1.7 ± 2.9	13.8 ± 3.2	9.7 ± 0.3
½	1	0.5%	½	5.3 ± 5.2	0.1 ± 0.2	13.0 ± 0.5	11.0
½	0	0.5%	1	6.2 ± 4.7	0.7 ± 0.3	11.9 ± 1.6	9.0
½	1	0.5%	1	7.8 ± 0.9	0.6 ± 0.6	13.0 ± 2.1	10.6 ± 2.3
½	0	0.5%	2	6.7 ± 2.4	1.1 ± 1.0	13.4 ± 2.2	12.0 ± 1.0
½	1	0.5%	2	5.9 ± 1.0	0.4 ± 0.5	12.9 ± 1.6	10.5 ± 2.5
0	0	0	0	15.4 ± 2.4	1.4 ± 0.7	23.3 ± 2.7	15.4 ± 2.7
Average minus IN-IIA				7.3 ± 1.4	1.2 ± 0.5	13.0 ± 1.0	10.2 ± 1.6
Average plus IN-IIA				6.3 ± 1.3	0.4 ± 0.15	13.0 ± 0.0	10.7 ± 0.3

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Grass height at the time of treatment was 11 inches for fescue and 7 inches for bluegrass.

Table 30. Comparison of 2,4-D Amine and Banvel (Dicamba) at Varying Rates in Combination with Embark on Seed Head Formation in Fescue and Bluegrass. Plots were located on an interchange on I-70 near Plainfield, IN. Applications were on April 27, 1982. Evaluations were on May 27. Applied by Dan Webel, 3M. Average of 3 replications.

		Seed Heads per ft^2		Seed Head Height, Inches	
Treatment	Lbs/A	Fescue	Bluegrass	Fescue	Bluegrass
None	-	14.4 ± 5.1	4.8 ± 1.9	28.2 ± 1.6	17.5 ± 2.7
Embark + 2,4-D	3/8 + 1	5.9 ± 2.0	4.8 ± 1.4	21.2 ± 1.4	11.3 ± 3.5
Amine	3/8 + 2	6.7 ± 4.2	5.1 ± 1.1	24.5 ± 2.1	12.9 ± 0.9
	3/8 + 3	3.3 ± 2.0	2.8 ± 2.2	21.0 ± 2.6	10.7 ± 7.2
Embark + Banvel	3/8 + ½	7.8 ± 3.5	4.3 ± 3.8	23.5 ± 0.7	11.2 ± 2.8
	3/8 + 1	6.9 ± 2.8	4.9 ± 1.5	22.6 ± 1.2	12.5 ± 1.6
	3/8 + 1½	4.2 ± 0.8	4.1 ± 1.3	20.2 ± 2.1	13.1 ± 1.6
Embark	3/8	1.9 ± 1.6	2.3 ± 0.9	18.4 ± 0.8	8.8 ± 1.0
Embark + Banvel +	3/8 + ½ + 2	6.7 ± 4.5	2.9 ± 1.3	22.8 ± 3.8	9.3 ± 1.2
2,4-D Amine	3/8 + 1 + 2	5.4 ± 4.0	6.3 ± 3.2	20.9 ± 1.4	13.0 ± 1.5
	3/8 + 1½ + 2	4.2 ± 2.2	5.4 ± 4.0	19.7 ± 3.2	11.8 ± 1.2
Embark + XM-12S +	3/8 + 1% + 3	0.9 ± 0.3	2.8 ± 2.4	12.5 ± 1.3	9.1 ± 1.9
2,4-D Amine					
Embark + XM-12S +	3/8 + 1% + ½	2.1 ± 0.9	2.7 ± 1.5	17.6 ± 5.9	8.2 ± 1.0
Banvel	3/8 + 1% + 1	1.7 ± 0.9	2.0 ± 1.2	17.3 ± 1.2	8.9 ± 1.2
	3/8 + 1% + 1½	1.7 ± 0.8	2.9 ± 1.0	17.3 ± 4.2	11.1 ± 1.7

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

interaction so that a mixture of 3/8 lb/A of Embark + 1% XM-12S + 1 or 1½ lb/A of Banvel (dicamba) gave 88% suppression of seed heads in fescue under the interchange conditions (Table 30).

A slight increase in effectiveness of Embark + 2,4-D Amine was seen in experiments where both additives IN-IIA and XM-12S were added together at near optimum rates for each additive alone (Table 29). To pursue this possibility further, a series of three tests were established in which the primary purpose was to test a 4-way mixture of Embark (½ lb/A as mefluidide) + IN-IIA (1 lb/A) + XM-12S (0.5% by volume) + 2,4-D Amine (2 lb/A acid equivalent). These results are presented in Tables 31 to 33. The experiments of Tables 31 and 32 are identical except that they were applied one day apart on May 9 and 10. The third experiment was applied 3 days later on May 13. All three experiments were applied very late when the fescue was about 12 inches tall and the bluegrass nearly 8 inches tall. Seed heads were beginning to form. Never the less, the 4-way mixture did perform well in all three tests, outperforming the 3-way mixtures in two of the three tests (Tables 31 and 33) on seed head formation in fescue and in all three tests (Tables 31, 32 and 33) on seed head formation in bluegrass. The percents suppression for fescue were 80, 72 and 84 respectively for the three experiments compared to 68, 93 and 68 for the 3-way mixture with XM-12S. For bluegrass, the percents suppression were 94, 79 and 86 respectively for the three experiments compared to 32, 21 and 61 for the 3-way mixture with XM-12S. If there is a problem with seed head suppression in bluegrass by the late application of the 3-way mixture with XM-12S, the addition of IN-IIA seemed to correct it adequately.

Because of the lateness of the tests, conclusions concerning the efficacy of the 4-way mixture must await confirmation in subsequent seasons. However, the low cost of the IN-IIA additive still makes this an attractive possibility.

Table 31. Comparisons of Additives IN-IIA and XM-12S in Combination with Embark and 2,4-D Amine on Seed Head Formation in Fesuce and Bluegrass. Plots were located adjacent to IN 126 in West Lafayette, IN. Applications were on May 9, 1982. Evaluation was on June 7. Each treatment was replicated three times.

Treatment, lb/A*				Seed Heads per ft^2		Seed Head Height, Inches**	
Embark	IN-IIA	XM-12S	2,4-D Amine	Fescue	Bluegrass	Fescue	Bluegrass
0	0	0	0	16.7 ± 6.0	3.4 ± 1.0	37.3 ± 4.5	20.7 ± 2.5
½	0	0	0	5.6 ± 0.6	3.6 ± 1.9	24.4 ± 3.3	17.4 ± 1.5
½	0	0.5%	0	4.6 ± 0.8	1.3 ± 1.3	18.3 ± 1.5	13.5 ± 0.7
½	1	0	0	4.2 ± 1.2	1.8 ± 1.8	18.8 ± 4.6	15.7 ± 3.3
½	1	0.5%	0	1.8 ± 1.5	1.0 ± 0.7	15.0 ± 2.0	11.7 ± 1.5
½	0	0	2	9.0 ± 4.8	3.3 ± 1.5	25.4 ± 5.8	16.9 ± 1.4
½	1	0	2	7.2 ± 2.1	1.8 ± 1.4	24.5 ± 3.4	16.3 ± 2.1
½	0	0.5%	2	5.3 ± 1.1	2.3 ± 1.0	20.5 ± 5.1	14.3 ± 1.5
½	1	0.5%	2	3.4 ± 2.2	0.2 ± 0.3	21.9 ± 3.3	9.0 ± 1.0

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Grass height at the time of treatment was about 12 inches for fescue and 8 inches for bluegrass.

Table 32. Comparisons of Additives IN-IIA and XM-12S in Combination with Embark and 2,4-D Amine on Seed Head Formation in Fescue and Bluegrass. Plots were located adjacent to IN 126 in West Lafayette, IN. Applications were on May 10, 1982. Evaluation was on June 8. Each treatment was replicated three times.

Treatment, lb/A*				Seed Heads per ft^2		Seed Head Height, Inches**	
Embark	IN-IIA	XM-12S	2,4-D Amine	Fescue	Bluegrass	Fescue	Bluegrass
0	0	0	0	21.4 ± 8.9	2.4 ± 1.1	36.0 ± 6.0	20.0 ± 4.6
½	0	0	0	8.8 ± 4.3	3.3 ± 1.5	21.9 ± 6.0	16.8 ± 6.3
½	0	0.5%	0	5.2 ± 0.7	2.2 ± 1.2	19.3 ± 2.0	17.5 ± 1.6
½	1	0	0	7.2 ± 3.0	1.2 ± 1.0	22.6 ± 8.0	17.4 ± 4.0
½	1	0.5%	0	2.6 ± 2.5	1.1 ± 0.9	19.1 ± 5.3	15.6 ± 2.9
½	0	0	2	12.7 ± 0.8	1.2 ± 1.0	28.7 ± 2.6	16.8 ± 4.5
½	1	0	2	11.0 ± 3.2	1.1 ± 0.9	25.1 ± 6.4	18.8 ± 7.3
½	0	0.5%	2	1.5 ± 1.0	1.9 ± 2.5	17.0 ± 2.8	15.0 ± 2.1
½	1	0.5%	2	6.0 ± 5.2	0.5 ± 0.5	19.6 ± 6.2	14.4 ± 1.0

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Grass height at the time of treatment was about 13 inches for fescue and 8½ inches for bluegrass.

Table 33. Comparison of a 4-Way Mixture of Embark + IN-IIA + XM-12S and 2,4-D Amine for Suppression of Seed Head Formation in Fescue and Bluegrass. Plots were located adjacent to IN-126 in West Lafayette, IN. Application was on May 13, 1982. Evaluation was on June 7. Each treatment was replicated three times.

Treatment, lb/A*				Seed Heads per ft^2		Seed Head Height, Inches**	
Embark	IN-IIA	XM-12S	2,4-D Amine	Fescue	Bluegrass	Fescue	Bluegrass
0	0	0	0	18.3 ± 3.5	4.4 ± 1.5	28.8 ± 1.6	16.4 ± 1.8
½	0	0.5%	2	5.8 ± 2.6	1.7 ± 1.5	18.3 ± 0.8	12.3 ± 1.5
½	½	0.5%	2	3.7 ± 1.3	1.2 ± 0.4	16.5 ± 1.2	11.3 ± 2.0
½	1	0.5%	2	2.9 ± 1.1	0.6 ± 0.5	14.4 ± 1.9	10.4 ± 1.6

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Initial height of fescue was 12 inches.

Because most of the road segments used in the growth inhibitor trials are included in the fall-spring 3-year cycle of herbicide application in the State, the weed population in the plots is relatively sparse and consists mostly of 2,4-D resistant or introduced (red clover/sweet clover) species. The clovers do, however, provide a reasonable index of the efficacy of 2,4-D, being in the moderately resistant category.

The antagonism between Embark and 2,4-D Amine was most obvious in terms of reduced weed control (Tables 34, 35 and 36). Weed control by 2,4-D Amine which normally averages 80 to 90% in this type of situation was either eliminated entirely (Table 34) or reduced to about 50% compared to Embark alone or untreated plots (Table 35 and 36) by the addition of Embark in the mixture.

Fortunately, the Embark-2,4-D antagonism for control of broad leaf weeds was alleviated by the XM-12S additive at 1% by volume in the mixture (Tables 34, 35 and 36). With the three-way mixture, weed control of 93, 80 and 60% was achieved depending upon the timing of the application.

It was interesting to note that with the early applications on April 12 and April 19, apparent control of both whorled and common milkweed was observed for the 3-way mixture of Embark + XM-12S + 2,4-D Amine (Tables 34 and 35). However in applications on May 6 and May 9 and 10, no control of milkweed was observed (Tables 36 and 37). The same was true for other 2,4-D-resistant species. A similar observation was made in 1981 with the additive K-104 + Embark + 2,4-D and should be pursued in subsequent investigations.

For 2,4-D susceptible species, there appears to be no problem. For these weeds, control with the 3-way mixture is between 80 and 100% and comparable to 2,4-D Amine alone at the same rates of application (Tables 38 and 39). Again, with the later applications, this time on May 12 and 13, milkweed was not controlled (Table 39).

Table 34. Control of Broad Leaf Weeds by 2,4-D Amine in the Presence of Embark and Various Additives. Plots were located in the median of US 52 west of Lafayette, IN, adjacent to golf course east of Wabash River. Applications were on April 12 and April 19, 1982. Each treatment was replicated three times. Evaluations were on August 11.

		Plants per 100 ft^2				
Treatment*	Lbs/A**	Whorled Milkweed	Sweet Clover	Red Clover	Other Weeds	Total
None		35	9	19	6	69
Embark Alone	¼, ½	15 ± 11	14 ± 4	11 ± 2	4 ± 5	30 ± 10
Embark + 2,4-D Amine	¼, ½ + 2,4	45 ± 39	3 ± 1	2 ± 3	1 ± 1	67 ± 14
Embark + 2,4-D Amine + IN-IIA	¼, ½ + 2,4 + 3/4	6 ± 9	1 ± 0	11 ± 3	1 ± 1	13 ± 3
Embark + 2,4-D Amine + XM-12S	¼, ½ + 2,4 + 1%	0 ± 0	1 ± 0	3 ± 5	1 ± 1	5 ± 6***

* Treatments averaged were as follow: Embark alone (½ and ½), Embark + 2,4-D Amine (¼ + 4, ½ + 4 and ¼ + 2), Embark + 2,4-D Amine + IN-IIA (¼ + 4 + 3/4, ½ + 4 + 3/4, and ¼ + 2 + 3/4), Embark + 2,4-D Amine + XM-12S (¼ + 4 + 1%, ½ + 4 + 1% and ¼ + 2 + 1%). Applied by Dan Webel, 3M.

** Rates are in pounds per acre of active ingredient except for XM-12S which is percentage of the total mixture.

*** 93% control of all weeds.

Table 35. Control of Broad Leaf Weeds by 2,4-D Amine in the Presence of Embark and Various Additives. Plots were located in the median of US 52 west of West Lafayette, IN, near the Purdue University Agronomy Farm. Applications were on April 19, 1982. Evaluations were on August 9, 1982. Each treatment was replicated three times.

		Weeds per 100 ft^2							
			Milkweed			Other	Wild	Red
Treatment*	Lbs/A**	Total	Whorled	Common	Total	Weeds	Carrot	Clover
Embark	¼, 3/8, ½	85±52	18±18	4± 4	22±22	53±39	7±6	45±13
Embark + 2,4-D Amine	¼, 3/8, ½ + 2	73±22	13±13	2± 1	15±14	37±26	8±7	21±14
Embark + 2,4-D Amine + IN-IIA	¼, 3/8, ½ + 2 + 3/4	88±54	55±55	1±1	56±56	38±30	7±5	21±6
Embark + 2,4-D Amine + XM-12S	¼, 3/8, ½ +2 + 1%	17±7***	1±1	1±1	2±2	15±9	7±5	9±8

* Treatments averaged were in all combinations of the rates given. For example, with Embark + 2,4-D amine, the treatments were ¼ + 2, 3/8 + 2 and ½ + 2. For Embark + 2,4-D Amine + XM-12S, the treatments were ½ + 2 + 1%, 3/8 + 2 + 1% and ½ + 2 + 1%, etc. Applied by Dan Webel, 3M.

** Active ingredient in pounds per acre except for XM-12S which is % of total mixture.

*** 80% control of all weeds. Red Clover was controlled by 80%, milkweed by 90% but no control of wild carrot was apparent.

Table 36. Control of Broad Leaf Weeds by 2,4-D Amine in the Presence of Embark and Various Additives. Plots were located in the median of US 52 west of West Lafayette, IN, near the Purdue University Agronomy Farm. Applications were on May 6 with evaluations on September 16. Each treatment was replicated three times.

		Weeds per 100 ft^2						
			Milkweed			Other	Wild	Red
Treatment*	Lbs/A**	Total	Whorled	Common	Total	Weeds	Carrot	Clover
None		226	4	2	6	1	55	164
Embark	¼, 3/8, ½	113±39	27±27	1±1	28±28	1±1	32±20	52±9
Embark + 2,4-D Amine	¼, 3/8, ½ + 2	89±32	29±29	6±3	35±33	0±0	14±1	40±20
Embark + 2,4-D Amine + IN-IIA	¼, 3/8, ½ + 2 + 3/4	377±147	310±115	2±2	312±115	2±2	25±7	38±27
Embark + 2,4-D Amine + XM-12S	¼, 3/8, ½ + 2 + 1%	93±34	65±39	3±4	68±42	0±0	22±7	3±5 ***

* Treatments averaged were in all combinations of the rates given. For example, with Embark + 2,4-D amine, the treatments were ¼ + 2, 3/8 ÷ 2 and ½ + 2. For Embark + 2,4-D Amine + XM-12S, the treatments were ½ + 2 + 1%, 3/8 + 2 + 1% and ½ + 2 + 1%, etc. Applied by Dan Webel, 3M.

** Active ingredient in pounds per acre except for XM-12S which is % of total mixture.

*** 60% control of all weeds. Red clover was controlled by 98% and wild carrot by 60% but milkweed did not appear to be controlled at all.

Table 37. Control of Broad-Leaf Weeds by 2,4-D Amine in the Presence of Embark and Additives XM-12S and IN-IIA. Plots were located adjacent to IN-126 in West Lafayette, IN. Applications were on May 9 and 10, 1982. Evaluation was on August 6. Each treatment was replicated six times.

Treatment, lb/A*					
Embark	IN-IIA	XM-12S	2,4-D Amine	Total Weeds/10 ft^2 **	% Control
0	0	0	0	3.6	
½	0	0	0	6.9	
½	0	0.5%	0	3.6	
½	1	0	0	0.7	
½	1	0.5%	0	4.2	
			Average, No 2,4-D	3.2	0
½	0	0	2	1.1	66
½	1	0	2	0.7	78
½	0	0.5%	2	2.7	16
½	1	0.5%	2	3.1	3
			Average, Plus 2,4-D	1.9	41

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Mostly 2,4-D resistant species consiting of wild carrot, milkweed, bull nettle and late composites (ironweed, goldenrod, aster).

Table 38. Effect of Additive XM-12S on Control of Broad Leaf Weeds by 2,4-D Amine in the Presence and Absence of Additive IN-IIA. Plots located along IN-126 in Lafayette, IN. Applications were on May 6, 1982. Evaluations were on August 3, 1982. Averages of results from three replications ± standard deviations.

Treatment, lbs/A*				Height** (inches)	Weeds per 10 ft^2						
Embark	IN-IIA	XM-12S	2,4-D Amine	Fescue	Carrot	Red Clover	Plantain	Dandelion	Other	Total	Control %
0	0	0	0	19.3±2.1	2.7±2.0	4.7±3.0	5.6±4.5	2.0±1.0	2.0±1.0	17.0	0
½	0	0.5%	½	14.0±2.6	0.7±0.6	1.0±1.0	0.0	0.0	0.3±0.7	2.0	88
½	1	0.5%	½	15.6±1.5	0.7±1.1	1.0±1.0	0.0	0.7±0.7	0.0	2.4	86
½	0	0.5%	1	13.3±2.0	0.0	0.3±0.3	0.0	1.3±1.5	0.3±0.7	1.9	89
½	1	0.5%	1	13.3±0.6	0.0	3.0±3.0	0.0	1.0±1.0	2.7±2.8	6.7	61
½	0	0.5%	2	14.0±1.7	0.0	0.6±0.6	0.0	0.7±0.7	1.0±1.0	2.3	86
½	1	0.5%	2	14.0±2.6	0.0	1.0±1.0	0.0	0.7±0.7	0.7±1.3	2.4	86

* Lbs per acre of active ingredient except for XM-12S which is given in percent by volume in the total mixture.

** Initial height at the time of treatment was about 11 inches.

Table 39. Control of Broad Leaf Weeds by 3-Way Mixture of Embark + XM-12S + 2,4-D Amine. Plots were located adjacent to IN-126 in West Lafayette IN. Application was on May 12 and 13, 1982. Evaluations were on August 6. Each treatment was replicated 6 times.

	Weed per 15 ft^2					
Treatment	Whorled Milkweed	Dandelion	Black Medic	Wild Carrot	Other	Total
None	3	13	3	2	1	22
3-Way Mixture*	3	1	0	0	0	4
% Control	0	92	100	100	100	82

* Embark ½ lb/A, XM-12S 0.5% and 2,4-D Amine 2 lb/A ± 0, ½ or 1 lb/A of IN-IIA.

All rates are as active ingredient.

A problem with control of broad leaf weeds much in evidence and not resolved by any of the mixtures thus far tested is that of wild carrot. Even with a timely application on April 19, wild carrot was much in evidence and even 7 plants per 100 ft^2 on an unmowed roadside creates an unsightly mess. This problem might be corrected by preceding the spring application of retardant material with a fall application of 2,4-D Amine to control the carrot but use of more potent herbicides in the mixture should also be considered.

A final series of studies was initiated in August, 1982 to provide preliminary information concerning the optimum concentration of XM-12S to be included with ½ lb/A of Embark (as mefluidide) and 2 lb/A of 2,4-D Amine. These results on growth of mowed bluegrass (Fig. 21) indicate that an optimum does exist that may be nearer 0.5% by volume than the 1% by volume recommended by 3M. Certainly, it is clear that too much (2%) and too little (0.1%) are ineffective. This observation cannot be extended to seed head formation in fescue without confirmation but, if confirmed, would result in considerable cost savings in terms of the reduced requirements for XM-12S in the mixture being considered for implementation.

5. Research Implementation: Applications of 2 pints Embark, 3/4 lb additive IN-IIA and 2 lb 2,4-D Amine in 40 gal of water per acre were scheduled for the spring of 1982 to US 52 west of Lafayette, IN by Don Bickel (Crawfordsville) and Dan Webel (3M) and in the Greenfield District on SR-3 Muncie Bypass by Clyde Mason. These applications were to be small tests of approximately 20 acres each. Unfortunately, the application rate of additive was on the low side (in retrospect 1 or 1.5 lb/A would have been preferable) but seed head suppression in fescue was still 83% and 88% in bluegrass in the Greenfield test (Table 40). The Lafayette test could not be evaluated due to difficulties resulting from equipment breakdowns during the application.

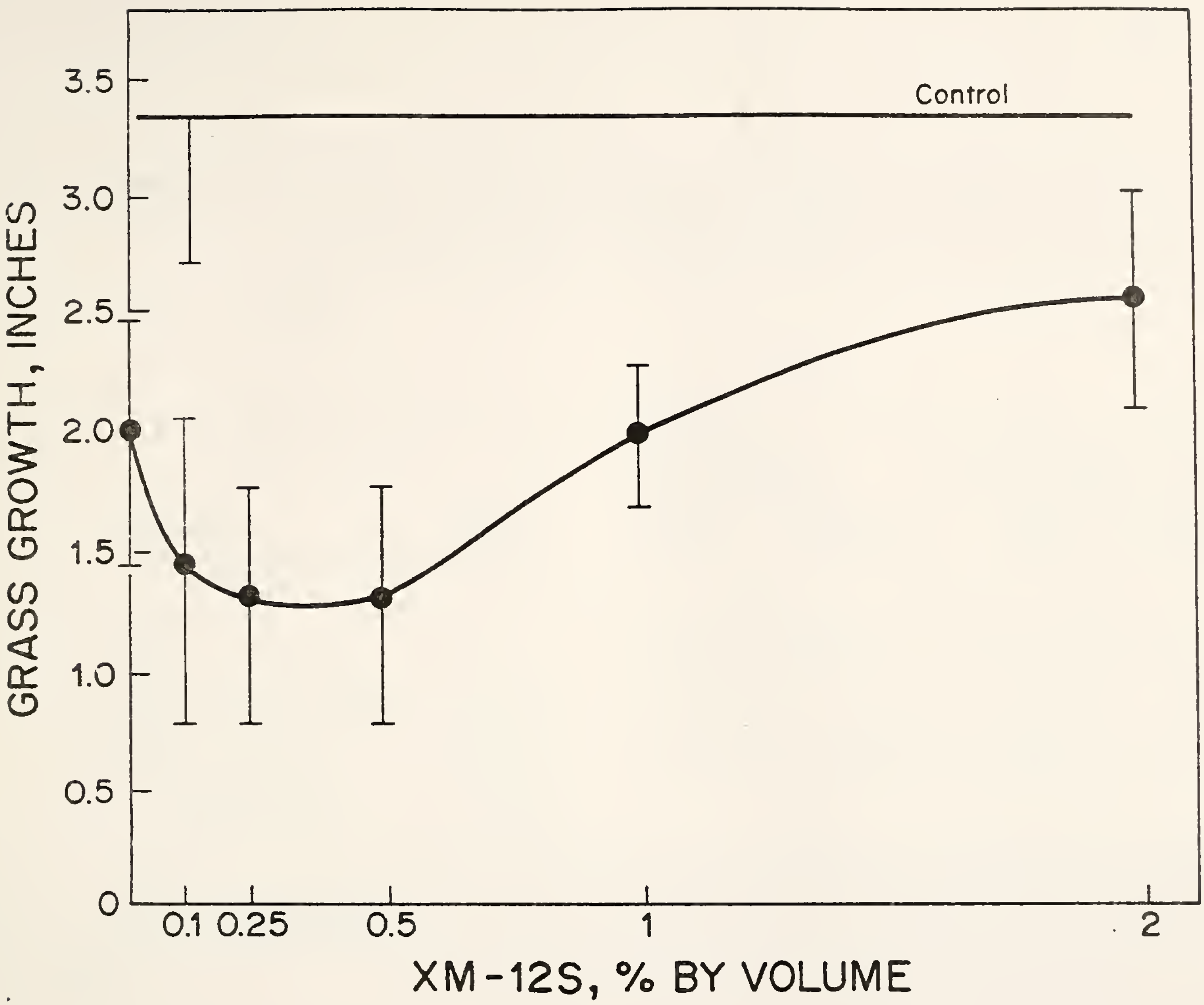

Figure 21. Effect of rate of application of XM-12S on growth of mowed bluegrass in the field in the presence of 1/2 lb/A Embark (as mefluidide) plus 2 lb/A of 2,4-D amine (acid equivalent). Applications were on August 8, September 9, September 11 and September 16, 1982. Each treatment was replicated three times. Measurements of growth were approximately 1 month after treatment. Values are the averages of the four experiments (12 replicates total) ± standard deviations.

Table 40. Evaluation of Embark + Additive IN-IIA and 2,4-D Amine Applied to SR-3 Muncie ByPass on April 21, 1982. Observations were on May 27.

		Seed Heads/ft^2		Seed Head Height, Inches	
Treatment	Lbs/A*	Fescue	Bluegrass	Fescue	Bluegrass
None	-	13.3 $\pm$ 1.1	10.6 $\pm$ 2.3	24.0 $\pm$ 2.0	10.0 $\pm$ 0.0
Embark + 2,4-D Amine	½ + 2.5	2.8 $\pm$ 1.0	0.7 $\pm$ 0.6	15.6 $\pm$ 2.1	7.6 $\pm$ 1.1
Embark + IN-IIA + 2,4-D Amine	½ + 3/4 + 2.5	2.2 $\pm$ 1.0	1.3 $\pm$ 0.6	15.2 $\pm$ 1.3	5.3 $\pm$ 1.5

* Active ingredient.

The test plots at Lafayette and the implementation tests in the Greenfield district were reviewed with John Burkhardt, Clyde Mason and Don Bickel of IDOH and Bill Howell and Dan Webel of 3M. A concensus view was reached that the new combinations were effective and that implementation of chemical mowing should continue for 1983.

In consultation with Mr. John Burkhardt, IDOH, plans have been completed to evaluate in the spring of 1983, 350 to 375 acres of the new chemical mowing combination of Embark + Additive XM-12S + 2,4-D amine as part of the roadside maintenance program of the State of Indiana. Materials are being purchased and no problems in completing this first phase of implementation are anticipated at the time of completion of this report.

6. Summary: Several materials were examined in detail for their ability to replace K-104 as an additive in the mixture with Embark. Both IN-IIA and XM-12S additives were effective in two-way mixtures with Embark and XM-12S was effective in three-way mixtures with both Embark and 2,4-D Amine. Four-way mixtures containing both additives at optimum rates of application plus Embark and 2,4-D Amine were also tested and may be advantageous in certain situations.

With IN-IIA the ratio of IN-IIA to Embark and to 2,4-D Amine appears to be more important that the absolute rate of application in determining effectiveness. The optimum ratio of IN-IIA to Embark in the presence of 2,4-D Amine was determined to be near 2:1 on an active ingredient basis. With XM-12S, detailed tests showed the optimum rate of application to be 0.5% by volume in the final spray mixture. More was not necessarily better.

Plans are to evaluate in the spring of 1983, 350+ acres of the new combination of Embark + Additive XM-12S + 2,4-D amine as part of the roadside maintenance program by contract for Indiana.

7. Reports:

Morre, D. J. 1978. Five-year evaluation of highway mowing practices in Indiana. Transportation Research Record 674: 47-53.

Morre, D. J. 1980. Evaluation of available herbicides and herbicide mixtures for control of brush and milkweed along roadsides. Interim Report Civil Engineering Joint Highway Research Project JHRP-80-1. 24 pp.

Morre, D.J. 1981. Influence of research and development on roadside management. Transportation Research Record 805: 11.

Morre, D. J. 1981. Chemical Mowing. Proc. 67th Annual Road School. Engineering Bulletin of Purdue University. Engineering Extension Series 152: 117-121.

Morre, D. J. 1981. Evaluation of contractual roadside maintenance (mowing and spraying) 1977-1979. Summary. Interim Report, Civil Engineering Joint Highway Research Project. 35 pp.

Morre, D. J. 1983. A new program of chemical maintenance of roadsides from Indiana. Transportation Research Record. Accepted for publication.

A report on the progress with the chemical mowing program in Indiana has been scheduled for presentation at the 62nd annual meeting of the Transportation Research Board in Washington, DC, on January 17, 1983. Results of laboratory tests were presented at the Annual Meeting of the Americal Society of Plant Physiologists in June of 1981 and again in June of 1982.

P H A S E I V

RECOMMENDATIONS, COST ESTIMATES, PROJECTED COST SAVINGS AND PRECAUTIONS

The following highlights from the report are considered in the recommendations that follow:

1) Embark alone at ½ lb/A is insufficient to control seed head formation in fescue at any date of application. This is especially true for fescue adjacent to the fence and pavement and when 2,4-D amine is present in the mixture (Table 41).

2) The XM-12S additive at 0.5 % by volume to the total spray mixture overcame any 2,4-D antagonsim and greatly enhanced the effectiveness of Embark with seed head suppression ranging from more than 90% on the roadside (Table 41) to 100% on interchanges (Table 42).

3) 2,4-D is required in the mixture to achieve control of broad leaf weeds and for control, through pre-emergence action, of annual grasses. Broadleaf weed control with the 3-way mixture of Embark + XM-12S additive + 2,4-D amine was comparable to that obtained by 2,4-D amine alone and in the range of 80 to more than 90% (Table 43).

4) Using the 3-way mixture, it has been possible to achieve full-season vegetation management along Indiana roadsides from a single spray application. The height of the vegetation going into the fall was just over 12 inches and mowing was not required (Table 44).

5) A "best" treatment selected for implementation in 1983 is ½ lb/A Embark (as mefluidide), 1% additive XM-12S (by volume) and 2 lb/A 2,4-D amine (acid equivalent). These recommendations are summarized in Table 45.

Table 41. Fescue Seed Head Suppression from Embark and Embark + XM-12S With or Without 2,4-D Amine. Abstracted from Table 32, page 87.

Treatment/Rate per acre	Seedheads per ft^2
None	21 ± 9
Embark, 1/2 lb/acre*	9 ± 4
Embark, 1/2 lb/acre + XM-12S, 0.5%	5 ± 1
Embark, 1/2 lb/acre + 2,4-D Amine, 2 lb/acre	13 ± 1
Embark, 1/2 lb/acre + XM-12S, 0.5% + 2,4-D amine 2 lb/acre	1.5 + 1

* Rates per acre of Embark refer to the active ingredient, mefluidide.

Applied on May 10 and evaluated on June 8, 1982.

Table 42. Seedhead Suppression and Growth Inhibition from Embark Alone and Embark Plus Additive Applied to Tall Fescue and Bluegrass. Abstracted from Table 27, page 80.

Embark		Seedheads/ft^2		Height, inches	
lb/A*	Additive	Fescue	Bluegrass	Fescue	Bluegrass
None	None	17 $\pm$ 3.5	8 $\pm$ 4	31 $\pm$ 4	18 $\pm$ 1
1/4		3 $\pm$ 1	5 $\pm$ 2	22 $\pm$ 1	11 $\pm$ 3
3/8		4 $\pm$ 1	3 $\pm$ 0	23 $\pm$ 2	13 $\pm$ 3
1/2		2 $\pm$ 1	1 $\pm$ 1	17 $\pm$ 2	11 $\pm$ 1
1/4	XM-12S 1%	1 $\pm$ 1	4 $\pm$ 1	17 $\pm$ 3	9 $\pm$ 2
3/8		1 $\pm$ 0	5 $\pm$ 4	13 $\pm$ 4	9 $\pm$ 2
1/2		0 $\pm$ 0	1 $\pm$ 1**	-	8 $\pm$ 3

* As mefluidide

** Seedheads formed were short, with a height less than that of the foliage.

Treatments were applied on April 27 with evaluations on May 27, 1982. Initial height of fescue = 10 inches. Initial height of bluegrass = 7 inches. Results are from 3 replicates $\pm$ standard deviations from the mean.

Table 43. Effect of Embark plus 2,4-D Containing Additive XM-12S on Control of Broadleaf Weed Species. Treatments applied May 13 with final evaluations on August 6.

Treatment Combination	Weeds per 15 ft^2	% Control
Unsprayed Check*	19	0
Embark, 1/2 lb/A** + 2,4-D amine, 2 lb/A	15	20
Embark, 1/2 lb/A + 2,4-D amine, 2 lb/A + 0.5% XM-12S	1	95

* Species present included wild carrot, dandelion, red clover, black medic, goldenrod, aster, buckhorn plantain, common plantain, milkweed and thistle.

** Rates per acre of Embark refer to the active ingredient, mefluidide.

Table 44. Fescue Height on September 16, 1982 Following Growth Retardant Application on April 19, 1982

Treatment/Rate per acre	Fescue height, inches
None	25 ± 5**
Embark, 1/2 lb/acre*	15 ± 1
Embark, 1/2 lb/acre + XM-12S, 1% + 2,4-D Amine, 2 lb/acre	13 ± 0

* Rates per acre of Embark refer to the active ingredient, mefluidide

Height of fescue at the time of treatment = 7 inches.

** Height of vegetative growth only. Does not include seed stalks.

RECOMMENDATION

Table 45. Program of Chemical Mowing to Be Implemented in 1983 in the Spraying-by-Contract Program

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Material: Embark (mefluidide) Plant Growth Regulator containing at least 2 lb active mefluidide per gallon plus 2,4-D amine form concentrate containing at least 4 lb acid equivalent per gallon (Ester formulations of 2,4-D are not used due to possible environmental hazards) plus Additive XM-12S.

Rate: Material is mixed at the rate of approximately 2/3 gallon of Embark (2 lb/gallon material) plus 1 1/4 gallons of 2,4-D amine (4 lb/gallon material) plus 1 gallon of XM-12S in 100 gallons of water. The mixture is applied at the rate of 40 gallons per acre.

Schedule of Application: Recommended for application in the spring only. Apply as soon as the grass begins to green until just before the emergence of seed heads from the boot (end of March to the first week of May in Indiana).

Cost saving information summarized in Table 46 is based on information provided by Mr. Kenneth Mellinger, IDOH in 1982. If adopted state wide. projected cost savings of between $400,000 and $1,500,000 annually are expected depending upon the number of actual mowings eliminated and the final configuration of the spray mixture.

The application of growth retardants must be far more precise that what is required, for example, with 2,4-D herbicide alone. A number of precautions which <u>must</u> be followed are summarized in Table 47. Above all, <u>the ratios of materials in the mixture should not be altered</u>.

Sources of the materials recommended are given in Table 48.

Table 46. Cost Estimate Information*

Costs	Gal/Acre	Cost/Acre
Embark = $105/gal	0.25	$26.25
XM-12S = 15/gal	0.4	6.00
2,4-D = 9/gal	0.5	4.50
Total material costs		$36.25
Estimated cost of application		8.75
Total costs		$45.00
Mowing costs (State average)		
$25/Acre X 2 cycles		$50.00
Net cost savings: to replace 2-cycle mowing		$ 5.00
to replace 3-cycle mowing		30.00

*Provided by Mr. K. M. Mellinger, Chief, Division of Maintenance, Indiana Department of Highways, Indianapolis, Indiana based on 1982 price information.

Table 47. Precautions

Embark, 1/2 lb per acre of mefluidide (0.25 gal per acre) is the lowest cost effective rate to prevent seed heads in fesuce adjacent to pavement and adjacent to fence. The temptation to reduce costs by using less should be suppressed.

Application must be uniform. Half of recommended rate may do nothing at all. Twice the recommended rate may kill native bluegrass.

Application must be timely. Grass sprayed after the seed heads have started to form will not be controlled. It is possible to begin spraying in the spring as soon as growth begins.

2,4-D or an equivalent broad leaf weed control agent must be included in the mixture if broad leaf weeds are to be controlled. If the weeds are allowed to grow, it will still be necessary to mow.

Do not use less that the recommended rate of 2 lb per acre of 2,4-D amine. The Embark/2-4-D antagonism may actually increase as the rate of the 2,4-D is lowered making the treatment less effective. Increasing the rate of 2,4-D much above 2 lb per acre is not worth the added cost. Ester formulations of 2,4-D are <u>not</u> recommended due to environmental considerations (volatility/possible fish kills if sprayed over open water).

The XM-12S additive must be mixed at or near the recommended rate of 1% (1 gallon per 100 gallons). By increasing or decreasing the amount of additive by more than a factor of two, effectiveness is reduced.

UNIFORM COVERAGE IS ESSENTIAL. EQUIPMENT MUST BE CALIBRATED CAREFULLY.

Table 48. Where to Obtain Materials

EMBARK 2-S Plant Growth Regulator is a product of
3M, Agricultural Products, Minneapolis/St. Paul

XM-12S is a product of WITCO Chemical Corp. 3230 Brookfield Street, Houston, Texas 77045.
<u>Specify</u>: Sponto-H3A (Exptl. No. 4948-16)

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